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Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (Phase I)

December 1994

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Naval Explosive Ordnance Disposal Technology Division
Project Manager: Gerard Snyder 301/743-6855
Senior Engineer: Andy Pedersen 301/743-6856
2008 Stump Neck Road
Indian Head, Maryland 20640-5070

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Army Environmental Center
Project Officer: Kelly Rigano 410/612-6868
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PRC Inc.
801 N. Strauss Avenue
Indian Head, MD 20640

Automated Research Systems, Ltd
4480 King Street - Suite 500
Alexandria, VA 22301

Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311-1772

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The report summarizes the results of unexploded ordnance technology demonstrations conducted at Jefferson Proving Ground, IN during April - October 1994. The purpose of this Congressionally mandated program was to identify and evaluate innovative and cost effective systems for the detection, identification and remediation of sites which have been contaminated with UXO.

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Executive Summary

This report presents the results of a technology demonstration project conducted to evaluate current and emerging systems and technologies for the detection, identification, and remediation of buried unexploded ordnance (UXO). The project objectives were to identify innovative systems or technologies and to acquire valid performance data through demonstrations conducted on a controlled test site.

Millions of acres of Government-owned, and formerly owned, properties are contaminated with UXO. The need exists to accurately and reliably assess the extent of contamination and to economically remediate the contaminated areas. House Resolution (H.R.) 2401 and H.R. 3116 mandated establishment of a program to demonstrate and evaluate advanced technologies and systems that can be used to characterize and remediate active and formerly used defense sites. In June 1993, the resulting program was established by the U.S. Army Environmental Center (USAEC), with the U.S. Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) as the technical lead. The initial phase of the program was an Advanced Technology Demonstration (ATD) project planned and carried out by NAVEODTECHDIV between August 1993 and December 1994. This project included development of a 120-acre controlled test site at the U.S. Army Jefferson Proving Ground (JPG) in Madison, Indiana; solicitation and selection of demonstrators of innovative technology; scheduling and monitoring of demonstrations; and evaluation of demonstration results. The ATD Program was open to all interested parties including U.S. and foreign companies and government agencies via the *Commerce Business Daily*, trade journals, and direct mailing.

The 120-acre controlled test site at JPG, consisting of a 40-acre area for ground system demonstrations and an 80-acre area for airborne systems, contains inert ordnance, non-ordnance, and debris carefully emplaced at depths and orientations typically found in UXO contaminated areas. The position of each emplaced object was measured by a licensed surveyor and recorded in a target database to provide a baseline against which demonstrator performance could be measured. A standardized data entry program was developed to ensure uniformity of demonstrator data submittals, and measures of effectiveness were developed to provide a technically meaningful framework for assessing demonstrator performance. The measures of effectiveness were based on a target matching algorithm development for this project and were expressed as target detection ratios (percentages of emplaced targets located by the demonstrators), classification ratios (percentages of emplaced targets correctly identified by the demonstrators), and error ratios (percentages of a demonstrator's reported targets declared to be ordnance that were not ordnance).

A total of 43 proposals were submitted for this phase of the project. The Government review panel selected 31 for demonstration. In addition, two proposals from Government laboratories, not funded under this project, were accepted. A total of 29 demonstrations were performed between April and October 1994, 4 of which were multimodal. The resulting 33

summaries are contained in the appendix. The demonstrators represented airborne, ground vehicle, and man-portable platforms; magnetometer, ground penetrating radar (GPR), electromagnetic induction, and infrared sensors; target processing software; and remediation technologies. Each demonstrator was scheduled for the test site and allotted a total demonstration time of 40 hours to be completed within a 7-day window. Demonstrator data was collected, entered into the target database, and analyzed using the target matching algorithm. Analysis of that data is presented in this report. The Government will present further detailed analysis of specific demonstrator capabilities in a separate report with limited distribution.

In general, all of the demonstrators performed well below the expected detection and identification capabilities. Ordnance detection ratios varied from 0 to 59 percent, with most ground-based systems scoring higher than airborne systems, and magnetometer sensors scoring better than GPR and other sensors. All demonstrators were generally unable to distinguish the emplaced non-ordnance debris from the inert ordnance targets. The lack of discrimination capability is also evident in the large numbers of targets declared as ordnance that did not correlate to any of the emplaced targets (false targets). Any capability to identify ordnance as belonging to a particular class of ordnance is thus opened to question in light of the above data. All but one of the airborne systems, and only a few of the ground-based systems, completed the survey of their entire area within the allotted 40 hour limit. Economic analyses of the demonstrators' search efforts are not included in this report. Measures of cost-effectiveness, such as cost per acre searched, will be incorporated into future analytical efforts.

The best performing search systems employed multiple platforms (such as vehicle-based and man-portable sensors), which is an indicator of probable future system developments. The remediation demonstrators showed that robotic remediation is feasible based on the transfer of target positions. However, robotic remediation is time consuming and could have a significant impact on operations if large numbers of targets require excavation. Again, economic measures, such as cost per item remediated, will be included in future analytical efforts.

The data obtained from the JPG demonstrations require qualification and further analysis. Absolute performance of demonstrators cannot be derived from the figures presented. The test protocol did not allow demonstrators to remove clutter or debris from the test area as they normally might; if they had done so, later demonstrators would have the advantage of a cleaner test area. In some cases, demonstrator movements were constrained because of the need to share the area with another demonstrator. The performance of the demonstrators also can be expected to vary with changes in the geophysical characteristics and type of UXO contamination found at other sites. Specific data on the test setup and demonstrator performance has been withheld from this report to prevent disclosure of information that could be used to determine the numbers and locations of ordnance targets. The Government, therefore, will be able to evaluate future demonstrations at the JPG test site on an equivalent basis.

The advanced technology demonstration program achieved its objective of identifying available systems and technologies for UXO detection, identification, and remediation. The data provided in this report allow the Government to conduct broad comparisons of sensors, platforms, and data analysis capabilities that performed in a known and controlled environment.

1 Introduction

1.1 Objective

This report presents the results of a technology demonstration project conducted to determine the capabilities of current and emerging government- and commercially developed systems and technologies for the detection, identification, and remediation of buried unexploded ordnance (UXO). The project objectives were to identify innovative systems or technologies, and to acquire reliable performance data using a controlled baseline to permit valid comparisons between individual systems and between classes of sensor technology.

1.2 Background

Millions of acres of Government-owned, and formerly owned, properties are contaminated with buried UXO. The need exists to accurately and reliably assess the extent of contamination and to economically restore the contaminated areas prior to reuse. Current technology used for restoration is costly, labor-intensive, and of questionable reliability. Congress mandated, via House Resolution (H.R.) 2401 (fiscal year 1993) and H.R. 3116 (fiscal year 1994), establishment of a program to demonstrate and evaluate advanced technologies and systems that can be used to characterize and remediate active and formerly used defense sites. The program was established in June 1993 with the U.S. Army Environmental Center (USAEC) as the lead agency. The USAEC tasked the U.S. Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) to take the technical lead.

The technology demonstration project was divided into two phases. Phase I included development of a controlled test site of 120 acres at the U.S. Army Jefferson Proving Ground (JPG) in Madison, Indiana; solicitation and selection of demonstrators of innovative technology; scheduling and monitoring of demonstrations; preparation of video and photographic records of demonstrations; development of a technology assessment database; and evaluation of demonstration results. Technical and logistical support for this phase was provided by PRC Inc., under contract N00600-88-D-3717/Delivery Order FG-3S. This report documents the Phase I effort that was carried out from August 1993 through December 1994. Phase II is planned to take place in 1995 at the 120-acre site at JPG. New demonstrators and JPG Phase I demonstrators who have made significant improvements in their respective systems are expected to participate.

1.3 Scope

The solicitation for Phase I demonstrations was open to all interested parties, including U.S. and foreign companies and government agencies. Innovative and

proven technologies capable of locating and identifying buried UXO were sought. Systems under development that had progressed far enough to operate in the field were also accepted. The systems selected for demonstration included man-portable, towed, and self-propelled ground systems, and fixed- and rotary-wing airborne systems. These systems represented the full range of current sensor technologies, including ground penetrating radars, magnetometers, and electromagnetic induction (EMI) and infrared (IR) sensors. Sensors designed to detect chemical compounds found in explosive materials were not demonstrated because only inert ordnance was emplaced on the test site. Systems and technologies designed primarily for processing sensor data, or for remediating UXO, were also included in the demonstrations.

1.4 Report Organization

This report presents detailed results of the technology demonstration project, organized to facilitate evaluation of individual systems/technologies or classes of systems/technologies. This report contains only the demonstration results and conclusions drawn from those results; further Government analysis and evaluation will be documented in a separate report. This report is divided into the following sections:

Controlled Test Site - this section provides a general site description and summarizes site preparation operations, including surveys to characterize the site geophysically and geomagnetically, site layout planning, acquisition and emplacement of inert ordnance and debris, and documentation of the baseline set of controlled targets.

Technical Approach - this section describes the process used to solicit and evaluate system or technology demonstration proposals, the procedures governing demonstration operations at the test site, the performance data collection process, and the measures of effectiveness used to correlate demonstration results with the test site baseline.

Systems and Technologies Demonstrated - this section lists the systems and technologies demonstrated, details of which may be found in the Appendix.

Demonstration Results - this section provides statistical summaries of the performance data collected during the demonstrations.

Discussion of Results - this section consists of a general discussion of the results of the demonstrations as well as specific observations on demonstrator performance, demonstration procedures, and other factors affecting interpretation or potential uses of the demonstration results.

Conclusions - this section presents conclusions that were drawn from the results presented in this report.

References - this section lists supporting documents that are referred to within the body of this report.

Appendix - the Appendix contains a brief description and the performance measures of effectiveness calculated for each system and technology demonstrated during this project, using the tabbing system described below.

Glossary - a glossary at the end of the report defines terms used in the body of the report that are unique to the JPG project and terms that have a unique application within this report.

A numbered and color-coded tabbing system has been used to facilitate location of demonstrator data and comparison of data by sensor type. The tabs are color-coded to indicate the class of technology that was demonstrated. The keys to the numbering and color coding systems are as follows:

Tab No.	**Platform**
	Airborne/Aerial Systems
1	Airborne, Fixed Wing
2 - 5	Airborne, Rotary Wing
6	Aerial
	Ground Systems
7 - 18	Ground, Man-Portable
19 - 29	Ground, Towed Platform
30	Ground, Self-Propelled
31 - 33	Remediation Systems

Color Code	Technology Demonstrated
Red	Ground Penetrating Radar (GPR)
Yellow	Magnetometer (M)
Green	Infrared (IR)
Black	Multisensor- GPR/IR
Dark Blue	Multisensor- GPR/Magnetometer
Light Blue	Magnetometer/Software
Brown	Remediation

2 Controlled Test Site

2.1 Site Location

Congress mandated the selection of JPG as the location for the controlled test site. JPG covers over 55,000 acres located in southeastern Indiana, approximately 65 miles southeast of Indianapolis (see figure 1). The range areas include firing lines and impact areas. The 120-acre controlled test site, located along JPG's eastern perimeter, consists of a 40-acre area (also referred to as the North Site) for demonstration of ground systems and an 80-acre area (also referred to as the South Site) for demonstration of airborne systems.

2.2 Site Preparation

2.2.1 **Preliminary Operations.** Prior to beginning site layout operations, all vegetation 4 inches or less in diameter was cut to a height of approximately 3 inches. Mobile offices were placed in both areas to provide desk space, electricity, telephones, and parking; sanitary facilities were also emplaced.

2.2.2 **Layout.** Both areas were divided into 100-foot by 100-foot grid cells, with the northeast corner of each area as the point of origin (grid cell A-1). Subsequent grid cells along the northern boundary of each area progress westward alphabetically, and grid cells along the eastern boundary progress southward numerically. The North (40-acre) Site measures 1,320 feet along the northern edge by 1,320 feet along the eastern edge (40.0 acres). The South (80-acre) Site measures 1,300 feet along the northern edge by 2,500 feet along the eastern edge (74.6 acres). Permanent benchmarks (surveyor's monuments) were established at each site as reference points for maps and for surveying emplaced targets. Three monuments were established within the North Site, and four were established within the South Site. The monuments were positioned in such a way that from any given monument another monument would be in the surveyor's field of view.

2.2.3 **Aerial Survey.** An aerial survey was performed to collect topographic measurements and identify the locations of vegetation, terrain features, and other features of interest. The aerial survey was conducted after JPG personnel had mowed the sites, and grids and monuments had been established. Elevation data points were established throughout and around the edges of each grid so that a detailed, 2-foot-interval contour model of each site could be constructed. The survey was referenced to the North American Datum (NAD) 83. U.S. Survey feet scales were used to conform to the grid layout and aerial survey scale. The control data were received

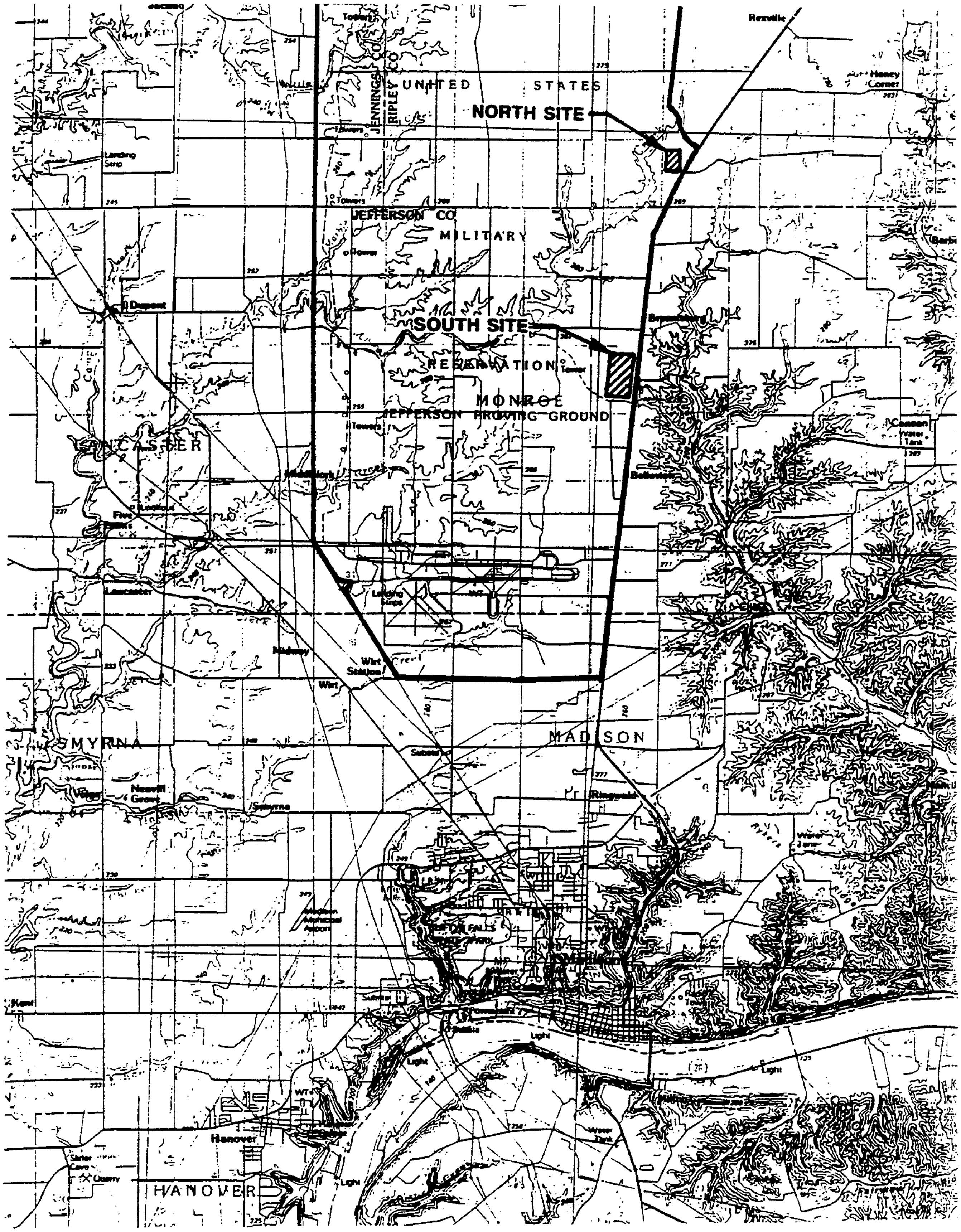


Figure 1 - Map of Jefferson Proving Ground Controlled Sites

from the aerial surveyor in digital format and were downloaded directly into an AutoCAD system, which produced the topographic maps of each site that were provided to each demonstrator.

2.3 Geophysical/Geotechnical Characterization

Geophysical and geotechnical surveys and investigations were performed to characterize the sites and provide input data for target emplacement planning. The same data were later provided to the demonstrators to assist them in properly calibrating their equipment. These activities are summarized in the following paragraphs. Detailed results of the characterization efforts are contained in the Area Report (see reference 1) appended to the Demonstrator Work Plan. Two additional surveys were performed prior to the start of demonstrations to provide additional baseline data for evaluation of demonstrator results.

2.3.1 **Geotechnical Investigations.** Soil probing was conducted at approximately 200 grid node locations in each of the test sites to determine the thickness of the soil layer over bedrock. A total of 20 geotechnical samples was collected from the two sites. Approximately one half were continuous samples bored down to the bedrock. These samples were used to characterize the soil layers. The remaining samples were taken at specific depths based on the layers previously identified. All 20 samples were subjected to testing for moisture content, soil density and homogeneity, granularity, permeability, and conductivity. Characteristics of the bedrock in the area were determined from published surveys.

2.3.2 **Geophysical Investigations.** Two magnetometer surveys were conducted at each site. The first survey was used to locate much of the magnetic surface debris. The second survey recorded magnetic field intensity levels at grid points and general background levels in the area. The data from the second survey were used to generate magnetic contour maps of each site. A resistivity survey was performed at each site to characterize soil resistivity. A GPR survey was conducted at random locations in each site to obtain representative electromagnetic characteristics.

2.3.3 **EOD Team Site Characterization.** The 75th Explosive Ordnance Disposal Detachment (EOD), Selfridge ANGB, Michigan, conducted a search for subsurface ferrous materials at the 40-acre area from February 14 through 25, 1994. EOD personnel used the man-portable MK22 Mod 0 Surface Ordnance Locator, a cesium-vapor, total-field magnetometer used to detect ferrous objects. Anomalies detected by the MK22 were classified as small (240 to 750 gamma); medium (over 750 to 2,000 gamma); or large (over 2,000 gamma). Each magnetic anomaly was marked with a stake, then was surveyed to determine X and Y coordinates. A total of 72

anomalies was located: 29 small, 24 medium, and 19 large. The survey also identified old fence lines and the remnants of farming equipment buried within the area. The NAVEODTECHDIV concluded that the subsurface debris would not hinder target emplacement operations and would be typical of UXO-contaminated sites, so the debris was left in place. All anomalies were plotted on an EOD target map.

2.3.4 **STOLS Characterization.** On March 7, 1994, the NAVEODTECHDIV's Surface Towed Ordnance Locating System (STOLS) was sent to JPG to assist in the demonstration site characterization effort. The STOLS consists of an array of seven cesium-vapor total-field magnetometers mounted on a platform towed by an all-terrain vehicle. The STOLS uses a differential GPS to determine the Universal Transverse Mercator (UTM) coordinates of an anomaly, and the STOLS software is able to estimate the size and depth of the target.

The STOLS team surveyed 22.5 acres of the 40-acre area during ordnance emplacement operations. The purpose of the survey was to establish a ground truth before demonstrations began. The STOLS survey team independently verified the location of selected targets and confirmed the presence of some of the anomalies found by the 75th Explosive Ordnance Disposal Detachment. A total of 76 anomalies was located; some of these targets corresponded to emplaced ordnance. As a result of the STOLS survey, the NAVEODTECHDIV concluded that conducting advanced technology demonstrations on the 40-acre area was practical, and that meaningful data could be obtained from the demonstrations.

2.4 Record of Environmental Consideration

A Record of Environmental Consideration (REC) was prepared in accordance with the environmental regulations of AR 200-2. Wetlands, endangered species, archeological, and agricultural studies were conducted. The Army approved a categorical exclusion to create and operate the site. Thus, no environmental assessment or environmental impact statement was required or prepared.

2.5 Safety, Health, and Emergency Response Plan

A Safety, Health, and Emergency Response Plan (SHERP) was prepared for on-site operations. The SHERP was written to include preventive and protective measures against health, physical, fire, and explosive hazards that could exist during site preparation and technology demonstrations. The plan incorporated safety standards and guidelines from the Occupational Safety and Health Administration (OSHA), the U.S. Environmental Protection Agency (EPA) Operating Safety Guidelines, the

National Institute of Occupational Safety and Health (NIOSH), and the U.S. Army Corps of Engineers Safety and Health Requirements Manual.

2.6 Baseline Target Selection and Layout

The objective of this effort was to realistically emulate UXO-contaminated areas within the constraints of available resources. The test site at JPG was designed to simulate the following three different UXO contamination scenarios: a military training area, an ordnance disposal site, and a formerly used defense site. An area contaminated with mines was also included at the request of another Government activity. The following procedure was used to accomplish that objective:

1. Define the data objectives of the demonstration.

2. Identify required types, sources, and availability of ordnance.

3. Characterize the orientation and depths of UXO.

4. Emplace the ordnance.

5. Establish a Reference Site.

2.6.1 Demonstration Data Objectives. The objective of demonstrations on the 40-acre area was to have a sufficient number of baseline ordnance and non-ordnance targets emplaced to compute probabilities of detection (defined by the distance between a demonstrator's target location and the ordnance item's true location), and false positive (defined as emplaced man-made objects declared incorrectly to be ordnance) and false negative (defined as demonstrator targets declared as ordnance that do not correlate to known baseline targets) statistics. Refer to the Glossary at the end of the report for more detailed definitions. The statistical significance of the data has been deliberately omitted in this report to avoid compromising the number of targets to potential Phase II demonstrators. The objective of the airborne system demonstrations on the 80-acre area was to detect large concentrations of buried ordnance items, primarily for the purpose of determining the boundaries and concentrations of potential UXO contamination.

2.6.2 Sources of Inert Ordnance. JPG was the preferred source for obtaining inert ordnance and false targets to avoid unnecessary transportation costs. Inert ordnance items 8 inches in diameter and smaller were available at JPG. Most of the inert ordnance items exceeding 8 inches in diameter, such as general purpose bombs, were obtained through the Chief of Naval Operations (N-11), from Eglin Air Force Base, Florida.

2.6.3 UXO Depth and Orientation Characterization. In order to develop the most realistic emulation of conditions found on UXO-contaminated sites at JPG and similar sites, it was necessary to determine what general target characteristics were most important in selecting and emplacing targets. Expert opinion was solicited from experienced ordnance disposal professionals. Previous research efforts (see reference 2) provided data relevant to JPG. A U.S. Army study (see reference 3) developed a generalized solution to estimate maximum UXO penetration. Bomb penetration data was also obtained from a report prepared by the NAVEODTECHDIV for the U.S. Army Corps of Engineers (see reference 4). Additional information from Formerly Used Defense (FUD) site cleanup operations was obtained from the Corps of Engineers, Huntsville Division. This information was used to select various false positives that would be encountered at a FUD site.

As a result of this research, the following general guidance was followed for emplacing UXO that would be expected to be found at a contaminated site such as JPG:

All 20 mm and 30 mm aircraft- and ground-delivered flat trajectory gunfire typically results in the projectile penetrating the ground no more than 12 inches, and coming to rest horizontal to the plane of the surface.

Mortar rounds are generally found within 48 inches of the surface. Orientation is typically between 45 and 90 degrees from the plane of the surface due to the high angle of trajectory.

Projectiles (76 mm to 8 inch) are typically found horizontal to, or at a slight angle from, the surface plane, at depths of from 1 to 12 feet.

General purpose bombs (250 to 2,000 lb.) have been found at depths exceeding 20 feet, and at no predictable orientation to the surface plane (most are assumed to rest horizontally or at a 5 to 45 degree angle to the surface plane).

Air-launched rockets (2.75 and 5 inch) are generally found at depths of between 3 and 8 feet. Orientation is typically between 45 and 90 degrees from the plane of the surface due to the angle of trajectory.

Submunitions are generally small, with no standard size or shape, and are dispensed from cluster bombs or artillery rounds. Therefore, submunitions

are normally found on the surface, although they may be buried by secondary explosions.

Anti-personnel mines are emplaced at shallow depths and are generally found within a few inches of the surface.

A comprehensive layout plan (see reference 5) showing quantities and locations of targets was prepared as a guide for the emplacement effort. The following list summarizes the ordnance items selected for emplacement:

Bombs:	2,000 lb.; 1,000 lb.; 750 lb.; 500 lb.; and 250 lb.
Projectiles:	8 inch, 175 mm, 155 mm, 152 mm, 106 mm, 105 mm, 90 mm AP, 76 mm AP
Rocket Warheads:	5 inch and 2.75 inch
Mortars:	4.2 inch, 81 mm, and 60 mm
Submunitions:	M-42 armor defeating bomblets
Land Mines:	TS-50 and VS-50 anti-personnel mines
Aircraft Cannon:	30 mm and 20 mm rounds

2.6.4 **Emplacement of Inert Ordnance and Debris in 120-Acre Site.** Inert ordnance, man made debris, and empty holes (holes that were dug and backfilled with no objects present) were emplaced at known locations according to the Area Layout Plan (ALP) (see reference 5). Precise locations were determined by optical surveying techniques. After emplacement operations, the surface areas were conditioned to remove visible evidence of target positions. The emplacement methodology is described in the following paragraphs.

Large and medium-sized targets were emplaced by digging a hole and placing the item in the hole at the desired azimuth and inclination angles. Smaller targets were either emplaced in clusters by digging a hole and placing a cluster of targets in the desired position, or singly by slant drilling to the desired depth and inserting the item in the drilled hole. Clusters of small targets were arranged in patterns typical of aircraft strafing or submunitions release. Land mines were emplaced at ground level in patterns typical of those encountered in recent international conflicts. Other materials were emplaced to simulate disposal pits, debris

from ammunition breakout, and other typical scenarios. After the targets were surveyed, the holes were backfilled and tamped.

Each target was surveyed optically after emplacement to determine its precise position. As the ordnance was being emplaced, a Niacom Total Station 2-second gun and prism were used to simultaneously record the precise X (easting), Y (northing), and Z (elevation) coordinates. Surveying of the ordnance emplaced in excavated holes was straightforward. After emplacement, a direct shot was taken using the top of the target at its approximate center of mass as the target location. However, a few pieces of ordnance were emplaced with a drill rig. Because some of these holes were drilled at an angle, the precise location of the ordnance was determined by trigonometric calculation. The ground was surveyed at the exact entry point of the drill to determine the coordinates for that point. The distance down the projected azimuth and the inclination angle were used to determine the coordinates of the target.

Survey information was downloaded directly from the survey instrument to a data collection device. This procedure limits errors and transpositions that might result from transcribing the data from one system to the other. After all targets were surveyed, a complete printout of all the XYZ coordinates was produced. Nodes were digitally placed on the site map at the location of each item. Two broken Geoprobe rods whose locations were entered manually were the only exceptions.

After all targets were emplaced and surveyed, both demonstration areas were tilled and reseeded to restore them to their natural state and to obliterate visible signs of target locations. Deteriorated ground conditions on the 40-acre area required the use of a large bog disk followed by a light field disk to achieve uniformity of the soil. The areas were seeded and fertilized by crop-dusting aircraft fitted with a dry material pump and nozzle. Seeding concentrations recommended by the State of Indiana were exceeded by 45 percent.

2.6.5 **Demonstrator Reference Site.** A demonstrator reference site was established near the 40-acre area. The purpose of the reference site was to give demonstrators an opportunity to test their sensors against known ordnance at known depths. The following targets were emplaced within the reference site: one 500-pound low drag bomb at a depth of 3.3 m, one 175 mm projectile at a depth of 1.8 m, one 106 mm High Explosive Anti-Tank (HEAT) round at a depth of 1.2 m, and one M-42 armor defeating bomblet at a depth of 0.1 m. The locations of the test/calibration rounds and the boundaries of the test/calibration site were marked with hubs and laths.

2.6.6 **Target Size.** For the demonstration, target size was defined as follows:

Small Target	0 - 99 mm (≈ 4 inch) diameter
Medium Target	100 - 199 mm (≈ 8 inch) diameter
Large Target	Over 200 mm in diameter

2.6.7 **Target Classification.** The reporting classifications available to demonstrators were: Bombs, Projectiles, Mortars, Mines, and Clusters. Rocket Warheads are included in the Projectile classification. Aircraft Cannon rounds (20 mm and 30 mm), and Submunitions were included in the Clusters classification.

3 Technical Approach

3.1 Selection of Demonstrators

3.1.1 **Solicitation for Technology Demonstrations.** Based on lists of potential candidates compiled by the NAVEODTECHDIV and USAEC, 260 individual solicitation letters were mailed. During October 1993, announcements were carried in the *Commerce Business Daily* (CBD) for 30 days, in the *Wall Street Journal* for 1 week, and in one issue of *Aviation Week and Space Technology*. In addition, the announcement was placed on the Test and Evaluation Community Network (TECNET) bulletin board. In response to the announcements, 162 requests for a Site Information Package were received by the deadline, November 15, 1993.

3.1.2 **Site Information Package.** On December 13, 1993, 162 Site Information Packages were sent to prospective demonstrators. The recipients were invited to submit a firm fixed-price proposal to PRC Inc., for the demonstration of innovative technology at the JPG controlled test site. The packages included background information concerning the UXO Technology Demonstration program and the technology demonstrations at JPG, information concerning the preparation of the proposal, and appropriate details of the JPG controlled test site and surrounding areas. Candidates were instructed to submit proposals by January 19, 1994.

3.1.3 **Technology Selection Evaluation Plan.** A Technology Selection Evaluation Plan (see reference 6) defined the evaluation and scoring procedures for proposals received from prospective demonstrators. The plan established objective, weighted scoring criteria based on technology innovation, applicability to long-range UXO clean up goals, costs to demonstrate the system, and the history/background of the system development.

3.1.4 **Technology Proposal Selection.** The Government Review Panel scored 43 proposals per the Technology Selection Evaluation Plan. The Institute for Defense Analyses (IDA) conducted an independent review of the proposed technologies and forwarded its comments to the Government Review Panel. The Government accepted 31 proposals based on the evaluation scores and available funding. Two Government laboratories were accepted outside this review process. Congressional funding was not used to support their demonstrations.

3.2 Technology Assessment Database

A Technology Assessment Database (TADB) was developed by Automation Research Systems, Limited (ARS) to manage the data from the UXO technology demonstration project at JPG. The TADB is a computer program developed for the Government to use in conducting analyses of the performance of the demonstrators. The TADB was designed using dBase IV and captures the following data:

3.2.1 **Geotechnical Information.** This information is presented in AutoCAD files and includes elevation of grid points, soil thickness maps, magnetic field contours, and bedrock topography maps for both the 40-acre and 80-acre areas.

3.2.2 **Baseline Target Information.** The TADB contains all target information associated with the emplaced inert ordnance and non-ordnance debris. That information includes target identification, position, orientation, and relevant physical characteristics, and is referred to as the Baseline Target Set. Demonstrators are evaluated by their ability to match the Baseline Target Set. IDA has independently validated the TADB target positions against the original position data generated by the surveyor.

3.2.3 **Site Condition Information.** This information includes meteorological information, soil and moisture conditions, and soil dielectric constants. These data were collected on a daily basis, and were periodically supplied to ARS in machine-readable form for entry into the database.

3.2.4 **Demonstrator-Supplied Company and Equipment Descriptions.** This information includes generic information that describes the company conducting the demonstration; the equipment used; the type of system; technology being demonstrated (detection, identification, and/or remediation); the participants in the demonstration; and special demonstration conditions. As part of the proposal process, this information was supplied in word processing format on disk as well as hard copy. ARS edited these descriptions and entered them into the database in a consistent format to allow for retrieval of pertinent information. Graphic information was scanned and linked to the descriptive data for each demonstrator.

3.2.5 **Demonstrator-Supplied Demonstration Results.** A database entry program was supplied to each demonstrator, providing means for complete entry of data from each demonstration. The data, when received in this format, were directly entered into the database without any editing. This ensured that any data errors that may exist were generated by the demonstrator, and no errors were introduced by transcribing data. In several cases, demonstrators opted to submit their data in a spreadsheet

format using the categories cited in the demonstration program. In these cases, the data were reformatted, but the content remained unedited. The data received addressed the following different sets of information:

Demonstration Conditions - Quadrant and zone location information, weather conditions, soil conductivity, humidity, temperature, and presence of surface water.

Target Identification Results - The processed information for each target identified, recorded in the Standard Target Data Set format sent to each demonstrator. Each target comprises one record in this format. The set of all targets reported comprises the Demonstrator Target Set for that demonstration.

Target Disposition - Excavation and disposition data from remediation demonstrations. Each target comprises one record in this format.

Additional information on the database can be found in the TADB Users Manual (see reference 7).

3.3 Target Matching Algorithm Development

ARS developed a Target Matching Algorithm for automated correlation of demonstrator target data with the Baseline Target Set. The objective of target matching is to find the best match between a baseline target and a demonstrator's target in terms of their location, depth, size, type, class, and orientation. The assumptions on which algorithm development was based were that a single algorithm would apply for all demonstrators regardless of platforms or sensors used, and that technically meaningful results would be produced using three critical matching radii (1 m, 2 m, and 5 m). The essential elements of the algorithm are described in the following paragraphs. IDA independently validated the performance of the algorithm to match the demonstrator targets to the Baseline Target Set. Additional details on the development of the algorithm are contained in reference 8.

3.3.1 Target Data Set Matching Definitions. The two basic target sets consist of the Demonstration Target Set D, and the Baseline Target Set B. These are represented by the Venn diagram in figure 2. These two sets are further divided into subsets of ordnance and non-ordnance as shown in the two small circles found at the bottom of the figure. The relationships between the basic sets and their subsets are used as a means for generating demonstrator performance statistics. Figure 2 shows the target sets with all

the possible combinations of intersections between the subsets. Each target set is defined as follows:

Demo Target Set (*D*) - All targets reported by a single demonstrator.

Demo Ordnance Set (*DO*) - Subset of *D* consisting of only ordnance targets, that is, targets of type either Single or Multiple as reported by the demonstrator.

Demo Non-Ordnance Set (*DN*) - Subset of *D* consisting of only non-ordnance targets, that is, targets of type either Non-ordnance or Others as reported by the demonstrator.

Baseline Target Set (*B*) - All baseline (emplaced) targets of a single test site, that is, either the 40-acre or 80-acre area.

Baseline Ordnance Set (*BO*) - Subset of *B* consisting of only emplaced ordnance targets.

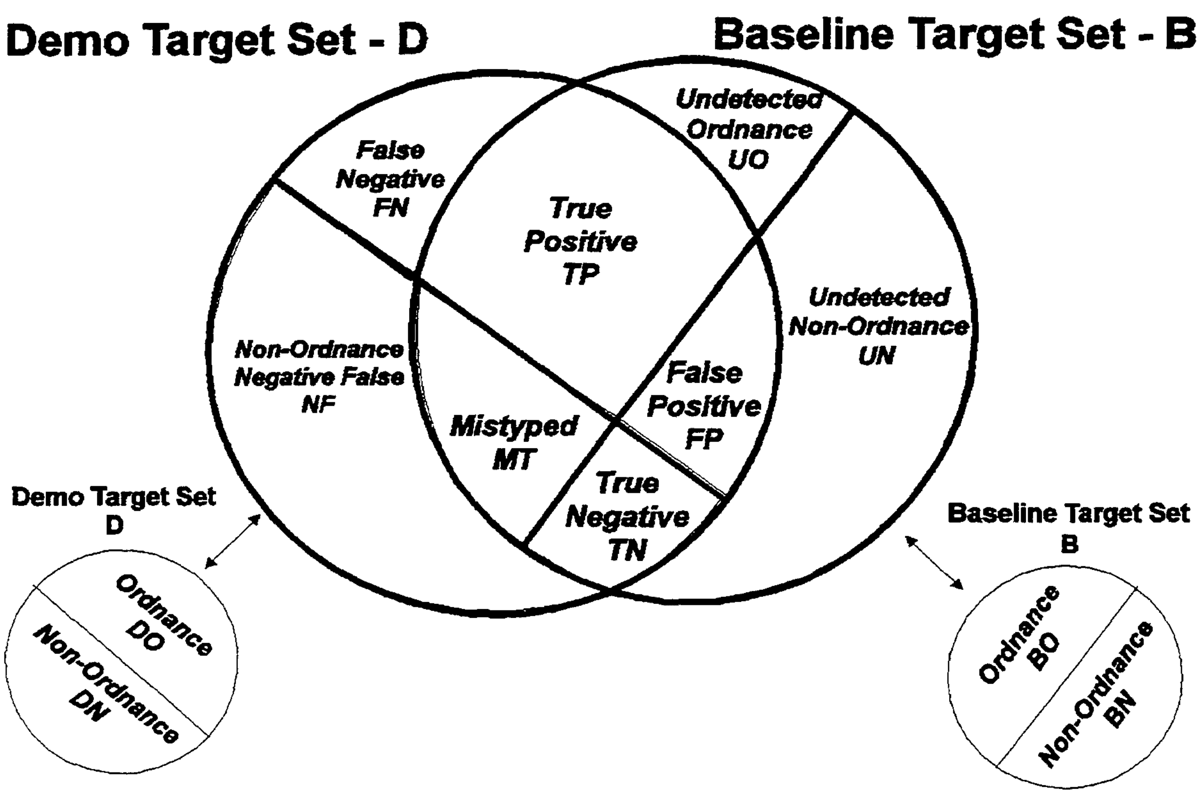


Figure 2. Target Evaluation Definitions Using a Venn Diagram

Baseline Non-Ordnance Set (*BN*) - Subset of *B* consisting of only emplaced non-ordnance targets.

Matched Target Set (*E*) - Baseline targets that are determined to be detected targets by the target matching algorithm. This information is not shown clearly in the Venn diagram, but it can be considered as the intersection between *D* and *B*, consisting of $TP + TN + FP + MT$.

True Positive Set (*TP*) - Baseline ordnance targets that are detected by the demonstrator and identified as ordnance (of either the single or multiple type). This represents the ordnance targets identified by a demonstrator that correctly match baseline ordnance targets. *A large number is desirable.*

Mistyped Target Set (*MT*) - Baseline ordnance targets that are detected by the demonstrator but are identified as non-ordnance (of either the non-ordnance or others type). This represents actual ordnance targets that are incorrectly identified as non-ordnance. *Zero or a small number is desirable.*

True Negative Set (*TN*) - Baseline non-ordnance targets that are detected by the demonstrator and are identified as non-ordnance (of either the non-ordnance or others type). This represents correctly identified non-ordnance targets. *A large number is desirable.*

False Positive Set (*FP*) - Baseline non-ordnance targets that are detected by the demonstrator but identified as ordnance (of either the single or multiple type). This represents an incorrect classification that would result in needless excavation of the target. *A low number is desirable.*

Undetected Ordnance Set (*UO*) - Baseline ordnance targets that are not detected by the demonstrator. This represents unremediated ordnance risks, and *a low number is desirable.*

Undetected Non-Ordnance Set (*UN*) - Baseline non-ordnance targets that are not detected by the demonstrator. While not causing any ordnance risk, this represents an insensitivity in the instrumentation. *A low number is desirable.*

False Negative Set (*FN*) - Demonstration ordnance targets that do not match any baseline targets. This represents target locations that must be excavated where no emplaced ordnance will be found. *A very low number is desirable.*

Negative False Set (*NF*) - Demonstration non-ordnance targets that do not match any baseline targets.

3.3.2 **Defining a Matching Condition.** As defined by the standard data set of the JPG TADB, each target (that is, either a demonstration target or a baseline target) is characterized by the following attributes:

Location: Target position in UTM coordinates.

Depth: Elevation measured from the mean sea level (MSL) to the center point of the target.

Size: Small, medium, or large.

Type: Single, multiple, non-ordnance, or others.

Class: Mortar, projectile, bomb, mine, cluster, or others.

Azimuth Angle: Angle between the target center axis and true north in the horizontal plane.

Declination Angle: Angle between the target center axis and the horizontal plane.

A demonstration target matches a baseline target if their attributes coincide, with location matching taking precedence. Tolerance limits can be introduced for attributes with numeric data types, that is, location, depth, azimuth angle, and declination angle. The match of each attribute is defined as follows:

Location match: A demonstration target *a* matches a baseline target *b* in location if the horizontal distance between *a* and *b* is less than or equal to the critical radius Δr, that is,

$$\sqrt{(X_a - X_b)^2 + (Y_a - Y_b)^2} \leq \Delta r$$

The horizontal distance is measured between the demonstrator target's stated position and the nearest surface of the baseline target, not the baseline target's center of mass.

Depth match: A demonstration target *a* matches a baseline target *b* in depth if the vertical distance between *a* and *b* is less than or equal to the critical height Δh, that is,

$$|Z_a - Z_b| \leq \Delta h$$

Size match: A demonstration target *a* matches a baseline target *b* in size, if both of them have the same size.

Class match: A demonstration target *a* matches a baseline target *b* in class, if both of them have the same class.

Type match: A demonstration target *a* matches a baseline target *b* in type, if both of them have the same type.

Azimuth angle match: A demonstration target *a* matches a baseline target *b* in azimuth angle, if the difference between the two azimuth angles is less than or equal to the critical angle $\Delta\alpha$, that is,

$$|\alpha_a - \alpha_a| \leq \Delta\alpha$$

Declination angle match: A demonstration target *a* matches a baseline target *b* in declination angle, if the difference between the two declination angles is less than or equal to the critical angle $\Delta\phi$, that is,

$$|\phi_a - \phi_b| \leq \Delta\phi$$

Based on the above definitions, the *matching indicator* of a target attribute is defined as a binary function to represent a match or mismatch for that attribute. Assuming that the target attributes are indexed in the order shown in the above list, for a given target pair *(a, b)*, the matching indicator for the *i*-th attribute m_i is equal to 1, if a match in the *i*-th attribute exists. Otherwise, it is set to *0.*

$$m_i^{ab} = \begin{cases} 1, \text{ if the matching condition for the I-th attribute is true} \\ 0, \text{otherwise} \end{cases}$$

The matching indicators were used during demonstrator data reduction to calculate detection ratios (total number of matched targets divided by total number of baseline targets) and classification ratios (number of matched targets divided by number of baseline targets of the same class). For purposes of data reduction, it was assumed that the same detection and classification ratio formulas would be applied to all demonstrators regardless of platforms or sensors used.

3.4 Measures of Effectiveness

The following output statistics, generated by the matching algorithm for each Demonstration Data Set, were used as the Measures of Effectiveness (MOE) for the Phase I demonstration project:

Detection Ratio:

Overall Detection Ratio (R_{all}) - number of matched targets divided by the total number of baseline targets in the grid cells surveyed. This ratio represents a demonstrator's detection capability in general.

Detection Ratio for Ordnance Targets (R_{ord}) - number of matched ordnance targets divided by the total number of baseline ordnance targets in the grid cells surveyed. This ratio represents a demonstrator's capability in detecting ordnance targets.

Detection Ratio for Non-Ordnance Targets ($R_{non\text{-}ord}$) - number of matched non-ordnance targets divided by the total number of baseline non-ordnance targets in the grid cells surveyed. This ratio represents a demonstrator's capability in detecting non-ordnance targets.

Detection Ratio for Small Targets (R_{small}) - number of matched targets of small size divided by the total number of baseline targets of small size in the grid cells surveyed. The targets must match in size only; targets may or may not match in type or class. This ratio represents a demonstrator's capability in detecting and identifying small targets.

Detection Ratio for Medium Targets (R_{medium}) - number of matched targets of medium size divided by the total number of baseline targets of medium size in the grid cells surveyed. The targets must match in size only; targets may or may not match in type or class. This ratio represents a demonstrator's capability in detecting and identifying medium targets.

Detection Ratio for Large Targets (R_{large}) - number of matched targets of large size divided by the total number of baseline targets of large size in the grid cells surveyed. The targets must match in size only; targets may or may not match in

type or class. This ratio represents a demonstrator's capability in detecting and identifying large targets.

Detection Ratio for Single Targets (R_{single}) - number of detected single targets divided by the total number of baseline single targets in the grid cells surveyed. This ratio represents a demonstrator's capability in detecting single ordnance targets.

Detection Ratio for Multiple Targets ($R_{multiple}$) - number of detected multiple targets divided by the total number of baseline multiple targets in the grid cells surveyed. This ratio represents a demonstrator's capability in detecting multiple ordnance targets.

Classification Ratio:

Classification Ratio for Bombs (C_{bomb}) - number of matched targets classified as bombs divided by the total number of baseline bombs. This ratio represents a demonstrator's capability in detecting and identifying bombs.

Classification Ratio for Projectiles ($C_{projectile}$) - number of matched targets classified as projectiles divided by the total number of baseline projectiles. This ratio represents a demonstrator's capability in detecting and identifying projectiles.

Classification Ratio for Mortars (C_{mortar}) - number of matched targets classified as mortars divided by the total number of baseline mortars. This ratio represents a demonstrator's capability in detecting and identifying mortars.

Classification Ratio for Mines (C_{mines}) - number of matched targets classified as mines divided by the total number of baseline mines. This ratio represents a demonstrator's capability in detecting and identifying mines.

Classification Ratio for Clusters ($R_{cluster}$) - number of matched targets classified as clusters divided by the total number of baseline clusters. This ratio represents a demonstrator's capability in detecting and identifying clusters.

Error Ratio:

False Positive Ratio (*FPR*) - number of false positive targets divided by the number of detected baseline non-ordnance targets. This ratio, which is the percentage of ordnance target declarations that were false targets, represents the likelihood that a demonstrator will recognize false targets as ordnance. A demonstrator who scores low (0) does well and has the capability to distinguish non-ordnance from ordnance. A demonstrator who scores high (1) does poorly and tends to declare everything detected to be ordnance.

$$FPR = FP/(FP + TN)$$

False Negative Ratio (*FNR*) - number of false negative targets divided by the sum of the numbers of false negative targets and true positive targets. This ratio is representative of the probability that a demonstrator will identify a false target as ordnance. A demonstrator with a low score does well. A demonstrator with a high score of say, 0.95, does poorly because 19 false targets will be reported for each ordnance item detected.

$$FNR = FN/(FN + TP)$$

Mistyped Ordnance Ratio (*MR*) - number of mistyped ordnance targets divided by the number of detected baseline ordnance targets. This ratio, which is the percentage of detected baseline ordnance targets declared as non-ordnance, represents the percentage of detected ordnance that would be missed due to the demonstrator's identification error. A demonstrator who scores low (0) does well because ordnance is identified correctly. A demonstrator who scores high (1) does poorly as most of the ordnance that is detected will not be investigated as ordnance targets.

$$MR = MT/(MT + TP)$$

Detection Accuracy:

The following items will be computed for ordnance, non-ordnance, each target type, and class:

Mean Distance (*MD*) - the average distance between matched target pairs.

$$MH = \overline{\Delta h} = \frac{\sum \Delta h_i}{N_E}, \ where\ N_E = |E|,\ \forall\ i \in E,\ \Delta D_i < \Delta r$$

Standard Deviation of Location (σ_D) - the root mean square of distance.

$$\sigma_h = \sqrt{\frac{\sum (\Delta h_i - \overline{\Delta h})^2}{N_E - 1}}, \ where\ N_E = |E|,\ \forall\ i \in E,\ \Delta D_i < \Delta r$$

Mean Depth (*MH*) - the average depth error between matched target pairs. Standard Deviation of Depth (σ_h) - the root mean square of depth error.

$$MD = \overline{\Delta D} = \frac{\sum \Delta D_i}{N_E}, \text{ where } N_E = |E|, \forall\, i \in E, \Delta D_i < \Delta r$$

3.5 Demonstration Procedures

3.5.1 **Demonstrator Work Plan.** Standard operating procedures were developed to control demonstrator operations at the test site. These procedures were promulgated in a Demonstrator Work Plan provided to each demonstrator. Each of the demonstrators was given a weekend to stage, set up, and test their equipment. The allowed time on the demonstration area was limited to 40 hours over the next 7 days. Demonstrators were required to conform to their proposed system configurations. They were not allowed to remove debris within the test area.

3.5.2 **Demonstration Data Capture.** Part of each demonstrator's tasking was to provide processed target data in the TADB format using a database entry diskette and instructions provided prior to the demonstration period. The database entry program was developed by ARS using dBase IV, with user friendly menu screens developed in Visual Basic. Detailed descriptions of the data collection process are contained in the TADB Users Manual (see reference 7).

3.5.3 **Remediation Systems.** The remediation demonstrators were provided the coordinates of baseline targets and were allowed to navigate to the target position. If necessary, the spot intended to be excavated was corrected to the baseline target location by using a handheld magnetometer so that the excavation process itself would be independent of system positioning errors.

4 Systems and Technologies Demonstrated

The JPG Phase I demonstrators are listed in table 1 by platform type. The demonstrators are not presented in any ranked order. Companies that used more than one platform, and companies that submitted more than one proposal, appear in more than one entry in the list. The list includes a reference to the numbered tabs in the Appendix where demonstrator results and system descriptions may be found. The tabs are color-coded as follows to indicate the type of sensor or technology demonstrated:

Color Code	Technology Demonstrated
Red	Ground Penetrating Radar (GPR)
Yellow	Magnetometer (M)
Green	Infrared (IR)
Black	Multisensor- GPR/IR
Dark Blue	Multisensor- GPR/Magnetometer
Light Blue	Magnetometer/Software
Brown	Remediation

Table 1 - JPG Phase I Demonstrators

	Tab No.
Airborne/Aerial Systems	
Fixed Wing Platforms	
SRI International (Fixed Wing)	1
Rotary Wing Platforms	
Geonex Aerodat, Inc.	2
Airborne Environmental Surveys (AES)	3
SRI International (Rotary Wing)	4
Oilton, Inc.	5
Metratek (Cancelled)	
Aerial Platforms	
Battelle (Airborne)	6
Ground Systems	
Man-Portable Systems	
Chemrad (GSM-19)	7
Arete Engineering Technologies Corporation	8
Chemrad (G-822L)	9
Australian Defence Industries (ADI)	10
Geo-Centers, Inc.	11
UXB International, Inc.	12
EODT Services, Inc.	13
GeoRadar, Inc.	14
Foerster Instruments, Inc.	15
Metratek (Ground)	16
Dynamic Systems, Inc.	17
Geometrics, Inc.	18
Towed Platforms	
Security Search Products (Vallon)	19
Australian Defence Industries (ADI)	20
Geo-Centers, Inc.	21
Chemrad (EG&G)	22
GDE Systems, Inc.	23
SRI International (Ground)	24
ENSCO, Inc.	25
Coleman Research Corporation	26
Foerster Instruments, Inc.	27
Metratek (Ground)	28
Battelle (Ground)	29
KAMAN Sciences Corp (Cancelled)	
Self-Propelled Systems	
Jaycor	30
BBN Systems and Technologies (Cancelled)	
Bristol Aerospace Ltd. (Cancelled)	
Autonomous Remediation Systems	
Benthos, Inc.	31
Sandia National Laboratories	32
Tyndall AFB Wright Laboratory	33

5 Demonstration Results

5.1 Demonstrator Data

The target data produced by each demonstrator was added to the TADB and was processed through the target matching algorithm to generate measures of effectiveness. The demonstrator target data has been deliberately omitted from this report to prevent Phase I data from being used to derive numbers and locations of emplaced ordnance and thus compromising the validity of Phase II demonstrations.

5.2 Target Matching Anomalies

The characteristics of the target matching algorithm are described in greater detail earlier in the report but some additional considerations are provided to interpret the following statistical results. The target matching algorithm first looks to see if more than one match exists between the demonstrator target and baseline targets within the critical radius (the horizontal distance between a demonstrator's coordinates and the boundaries of a baseline target that is projected onto the horizontal X-Y plane). The algorithm simplifies the baseline target as a cylinder with length, diameter, azimuth, and declination. Its projection on the X-Y plane is defined as a rectangle. For example, a baseline target with a 90° declination will appear as a square with sides that are equal to the target's diameter. For a hypothetical projectile that is 4 ft in length with a cylindrical diameter of 1 ft, a declination of 0°, and an azimuth angle of 90°, the rectangle projected in the X-Y plane (at the surface) will be 4 ft long and 1 ft wide, with the long axis in an east-west direction. The relative distance is calculated based on three different cases depending on the location of the demonstrator target center-point with respect to the projected baseline target rectangle.

When more than one baseline target is present at a specified critical radius, the target matching algorithm no longer matches solely on the basis of location and the matching characteristics may change significantly. These characteristics are depth (with a weight of one half of the distance), size (with a weight of one half of the depth), type (with a weight of one half of the size), and so on. If only one target is located in the critical radius, a match is made with that target only on the basis of location, but it is assigned the characteristics of the matched baseline target. As the critical radius increases, a greater chance exists that multiple baseline targets will be located within the critical radius. When this occurs, the matching process may pair the demonstrator target with a different baseline target because characteristics other than distance may match more closely. As a result, both size and classification ratios may change in ways that seem contrary to conventional logic. This occurs in several places in the demonstrator data. For example, the Large Targets Detection Ratio for Chemrad (EG&G) (tab 22) decreases from 35 percent to 34 percent when

the critical radius increases from 2 m to 5 m. In this case, demonstrator targets in the bigger area were correctly matched to medium baseline targets, increasing the Medium Targets Detection Ratio from 41 percent to 69 percent. Another example is EODT Services, Inc. (tab 13), where the reverse occurred; medium targets were reclassified as large targets. In another case, Geometrics, Inc. (tab 18), multiple targets were classified at 1 m critical radius, reclassified at 2 m, and reclassified again at 5 m, leading to Multiple Target Classification Ratios of 13 percent, 0 percent, and 13 percent, respectively. Although these data appear to be anomalies, the reclassifications by the algorithm are correct.

5.3 Demonstrator Performance Summaries

A summary of the measures of effectiveness for each demonstrator is presented on a separate page in the appendix. Each summary is tabbed and color coded as indicated in table 1 and on page 28. Measures of effectiveness were calculated for each of the 26 demonstrators of target detection, location, and identification systems or technologies. The measures of effectiveness are defined on page 24. Remediation results are presented on page 36. The following paragraphs discuss the data elements that are presented for each demonstrator, and characteristics of the data that may assist the reader in interpreting the data.

5.3.1 **System Description.** A brief description of mission-related system components, demonstration dates, and area covered are provided in the top block for each demonstrator.

5.3.2 **Measures of Effectiveness**. Measures of effectiveness are shown for each of the three critical radii (1 m, 2 m, and 5 m) used in the target matching algorithm to determine a location match. If a demonstrator target is not within the critical radius, it is considered a miss. If only one baseline target exists within the critical radius from the demonstrator target, a match is made and depth, type, and class of target are matched. If more than one baseline target is within the critical radius, then matching of size, depth, class, and orientation are used to determine which baseline target should be matched to the demonstrator target. As the critical radius is increased from 1 m to 2 m to 5 m, more target matches occur, as expected. However, in some cases, the type and classification ratios decrease at the 5 m radius because of the previously described target matching anomalies. The following Measures of Effectiveness are presented for each demonstrator:

Detection Ratios. The first two data blocks in the left column provide the demonstrator's detection ratios; first overall and by ordnance/non-ordnance targets, then by target type (single/multiple) and

by size (small, medium, and large). Ratios are rounded to the nearest whole percent.

Detection Accuracy. Detection position (distance) and depth accuracy data are provided for overall targets in the bottom block of each column. The data provided are the statistical mean, or average miss distance in meters, and standard deviation, which is indicative of the statistical distribution of miss distances. Because the matching algorithm measures the critical radius from the surface of the target and miss distances are measured from the target's center of mass, miss distances may be greater than the critical radius, particularly for larger targets.

Error Ratios. False Negative, False Positive, and Mistyped Ordnance ratios are provided in the top block of the right column. The False Positive Ratio (*FPR*) was designed to measure a demonstrator's ability to distinguish baseline non-ordnance targets from the baseline ordnance targets. Several demonstrators reported all targets as non-ordnance or made no attempt at target discrimination. Since they have no False Positive targets, their *FPR* would be zero. Although a low *FPR* is desirable, the zero result for these demonstrators is misleading because they demonstrated no ability for discriminating non-ordnance targets. Another set of demonstrators declared all targets as ordnance. In this case the *FPR* becomes 100 percent, which is more a measure of not attempting to discriminate than an indication of poor performance. These extreme cases are footnoted in the results, and the *FPR* is calculated only for those demonstrators who reported targets in both categories.

The False Negative Ratio (*FNR*) was designed to identify those demonstrators who declared excessive numbers of targets that were not matched to the Baseline Target Set. It was recognized that a 100 percent probability of ordnance detection was achievable just by declaring enough target positions to cover 100 percent of the demonstration area. Those demonstrators who declared all targets as non-ordnance would have an undefined *FNR* because they would have no ordnance targets, and applications of the formula would result in division by zero. The *FNR* is not used for those demonstrators, as indicated in the results. The *FNR* is valid for demonstrators who identified every target as ordnance. These cases are noted in the demonstrator results, and the *FNR* is shown. Otherwise, low scores indicate good performance and high scores indicate poor performance.

5.4 Data Summary

Demonstrations were conducted at JPG between April 23 and October 2, 1994. Of the 33 demonstrators selected for Phase I, 29 demonstrations were performed and 4 were cancelled by the demonstrators. The overall results of the demonstrations are summarized in tables 2 through 5 and the following paragraphs.

5.4.1 **Airborne System Performance for a 5-Meter Critical Radius.** (See table 2.) Five of the six airborne systems surveyed the entire 80-acre area. Three demonstrators employed ground penetrating radar systems; one used both active electromagnetic induction and passive magnetometer sensors; one used an infrared sensor system; and the sixth employed a combination of ground penetrating radar and infrared sensors. Weather conditions varied and affected each of the helicopter and fixed-wing flight operations to different degrees. These effects have not been taken into account and are beyond the scope of this study. Additional analysis of the data collected during the demonstration period will be required to fully assess the technology.

5.4.2 **Ground Based System Performance for a 2-Meter Critical Radius.** (See table 3.) Only four of the 20 ground based systems surveyed the entire 40-acre area during the allotted time. The 40-acre area was designed on the premise that each of the demonstrators would survey the entire area. However, many of the demonstrated systems were not designed for field operations and some demonstrators declined to utilize the full time alloted for the survey. As a result of the variances in the area surveyed, the comparison of performance among the demonstrators will entail further evaluation. There were four multimodal (vehicular towed system coupled with a man-portable adjunct) systems, eight man-portable (including man-towed) systems, and eight vehicle-towed ground-based systems demonstrated. Eleven employed active electromagnetic induction or passive magnetometers (some used both, but results are not separately identified), six used ground penetrating radars, and three were multi-sensor systems composed of both ground penetrating radar and active electromagnetic sensors or passive magnetometers.

5.4.3 **Detection Ratios and Area Coverage Performance by Platform and Sensor Type.** The data contained in tables 2 and 3 have been aggregated into groups of like technology (for example, the three airborne ground penetrating radar systems, the four multimodal ground-based systems, the three multi-sensor ground-based systems, and so forth) in order to arrive at a statistical mean within each grouping. The aggregate results are presented in table 4.

Table 2

Airborne System Performance for 5 meter Critical Radius						80 Acre Area	
Demonstrator - I.D.	Platform	Sensor Type1	Overall Detection Ratio	Ordnance Detection Ratio	False Positive Ratio	False Negative Ratio	Search Coverage
AES - 3	Air	G/I	1%	1%	*	95%	100%
Battelle (Airborne) - 17	Air	G	0%	0%	*	100%	36%
Geonex - 35	Air	M	4%	4%	100%	95%	100%
Oilton - 30	Air	I	8%	7%	**	**	100%
SRI (Fixed Wing) - 20	Air	G	3%	2%	-	97%	100%
SRI (Rotary Wing) - 21	Air	G	0%	0%	-	100%	100%

[1] G = GPR, M = Magnetometer (Active & Passive), I = Infrared, G/I = Multisensor

* Demonstrator did not discriminate between ordnance and non-ordnance targets

** Demonstrator declared all targets as ordnance

Table 3

Ground System Performance for 2 meter Critical Radius						**40 Acre Area**	
Demonstrator	**Platform[1]**	**Sensor Type[2]**	**Overall Detection Ratio**	**Ordnance Detection Ratio**	**False Positive Ratio**	**False Negative Ratio**	**Search Coverage**
ADI - 31	H/V	M	48%	46%	92%	74%	100%
ARETE - 19	H	M	17%	16%	89%	67%	55%
Battelle (Ground) - 16	V	G	7%	0%	*	100%	5%
CHEMRAD (GSM-19) - 6	H	M	5%	4%	100%	97%	100%
CHEMRAD (G822-L) - 7	H	M	28%	27%	**	**	100%
CHEMRAD (EG&G) - 10	V	M/G	13%	9%	100%	97%	35%
Coleman - 23	V	M/G	33%	36%	100%	94%	88%
Dynamic Systems 36	H	M	35%	29%	*	65%	12%
ENSCO - 29	V	G	3%	4%	*	100%	23%
EODT - 25	H	M	7%	7%	*	87%	24%
Foerster - 44	H/V	M	41%	37%	100%	89%	52%
GDE - 2	V	G	23%	32%	*	99%	16%
GeoCenters - 1	H/V	M	47%	44%	100%	76%	100%
Geometrics - 43	H	M	23%	24%	100%	74%	83%
GeoRadar - 42	H	G	14%	20%	*	96%	4%
Jaycor - 22	V	G	0%	0%	*	100%	46%
METRATEK - 33	H/V	M/G	25%	31%	*	90%	11%
Security Search - 37	V	M	65%	59%	*	98%	29%
SRI (Ground) - 24	V	G	1%	0%	**	**	29%
UXB - 13	H	M	43%	36%	**	**	70%

[1] Transport Mode, V = Vehicular/Towed, H = Handheld/Manportable/Man-towed, H/V = Multimodal

[2] G = GPR, M = Magnetometer (Active & Passive), M/G = Multi-Sensor

* Demonstrator did not discriminate between ordnance and non-ordnance targets

** Demonstrator declared all targets as ordnance

Table 4

Detection Ratios and Area Coverage Performance by Platform And Sensor Types				
Classification	**Demonstrator**	**Overall Detection Ratio**	**Ordnance Detection Ratio**	**Search Coverage**
Air - GPR	Battelle (Airborne)	0%	0%	36%
	SRI (Fixed Wing)	3%	2%	100%
	SRI (Rotary Wing)	0%	0%	100%
Mean		1%	1%	79%
Air - Infrared	Oilton	8%	7%	100%
Air - Magnetometer	Geonex	4%	4%	100%
Air - Multi-sensor	AES	1%	1%	100%
Ground - Multimodal	ADI	48%	46%	100%
	Foerster*	41%	37%	89%
	GeoCenters	47%	44%	100%
	METRATEK*	25%	31%	90%
Mean		40%	40%	95%
Ground - Multi-Sensor	CHEMRAD (EG&G)	13%	9%	35%
	Coleman	33%	36%	88%
	METRATEK*	25%	31%	90%
Mean		24%	25%	71%
Ground - Magnetometer	ADI	48%	46%	100%
All Transport Modes	ARETE	17%	16%	55%
	CHEMRAD (GSM-19)	5%	4%	100%
	CHEMRAD (G822-L)	28%	27%	100%
	Dynamic Systems	35%	29%	12%
	EODT	7%	7%	24%
	Foerster*	41%	37%	89%
	GeoCenters	47%	44%	100%
	Geometrics	23%	24%	83%
	Security Search	65%	59%	29%
	UXB	43%	36%	70%
Mean		33%	30%	69%
Ground - GPR	Battelle (Ground)	7%	0%	5%
All Transport Modes	ENSCO	3%	4%	23%
	GDE	23%	32%	16%
	GeoRadar	14%	20%	4%
	Jaycor	0%	0%	46%
	SRI (Ground)	1%	0%	29%
Mean		8%	9%	21%
* Appears in more than one classification				

5.4.4 **Remediation Results**. Three remediation systems were demonstrated between September 24 and October 2, 1994. The result of each remediation attempt is shown in table 5. These results, with additional data, are summarized in the (brown) tabbed pages in the Appendix.

Each demonstrator was provided target coordinates and used their own navigation system to get to the approximate target location. In order to remove any navigation error bias, the position was verified, or corrected if necessary, using a MK26 Ordnance Locator and a Vallon Ordnance Locator prior to excavation. In some cases, the target was flagged for the remediator so there was no positioning error. An estimate of the demonstrator's error in positioning the target is reported in the results, where applicable.

Table 5. Remediation System Results[1]

No.	Target Object	Depth (m)	Position Error (m)	Excavation Time[2] (hr)	Results
Benthos, Inc. (Tab 31)					
1	60 mm Mortar	0.3	11.0	0.5[3]	Navigation system error; Target manually located and retrieved
2	106 mm HEAT Round	1.1	0.6	2.5	Found, hand retrieved due to mud
3	250 lb Bomb	1.2	0.2	1.8	Found and retrieved
4	155 mm Projectile	0.8	1.2	1.0	Found and retrieved
5	60 mm Mortar	0.9	2.4	1.5	Found and retrieved
6	90 mm Projectile	2.1	0.3	3.5	Found and retrieved
7	81 mm Mortar	0.2	0.3	0.5	Found and retrieved
8	81 mm Mortar	0.4	1.0	0.8	Found and retrieved
9	175 mm Projectile	0.6	0.0	0.3	Found and retrieved
10	152 mm Projectile	0.8	-[4]	1.0	Found and retrieved
11	250 lb Bomb	1.7	1.5	2.5	Found and retrieved
Sandia National Laboratories (Tab 32)					
1	TS-50 A/P Mine	0.1	n/a[5]	0.6	Found and retrieved
2	TS-50 A/P Mine	0.1	n/a[5]	0.6	Found and retrieved
3	TS-50 A/P Mine	0.1	n/a[5]	0.6	Found and retrieved
4	TS-50 A/P Mine	0.1	n/a[5]	0.6	Found and retrieved
5	TS-50 A/P Mine	0.1	n/a[5]	0.6	Found and retrieved
Tyndall AFB Wright Laboratory (Tab 33)					
1	81 mm Mortar	0.3	0.6	0.8	Found
2	60 mm Mortar	0.3	0.6	0.8	Found
3	Unknown Anomaly	1.1[6]	0.0[5]	0.5	Ferritic debris found
4	500 lb Bomb	2.4	9.1[7]	2.5[3]	Not found due to navigation error
5	Unknown Anomaly	1.6[6]	9.1[5,7]	0.6	Ferritic debris found

Notes:
1 Remediation results reflect data extracted from field notes. In some cases, the data vary from the data reported by the demonstrators
2 All excavation times are estimated
3 Excavation was halted after determining there was no target at the original position; object was then located with a handheld magnetometer, excavated, and retrieved
4 Positioning error was not determined
5 Target locations were marked for the demonstrator
6 Estimated
7 Position error attributed to human-induced navigation error

6 Discussion of Results

6.1 Test Design Considerations

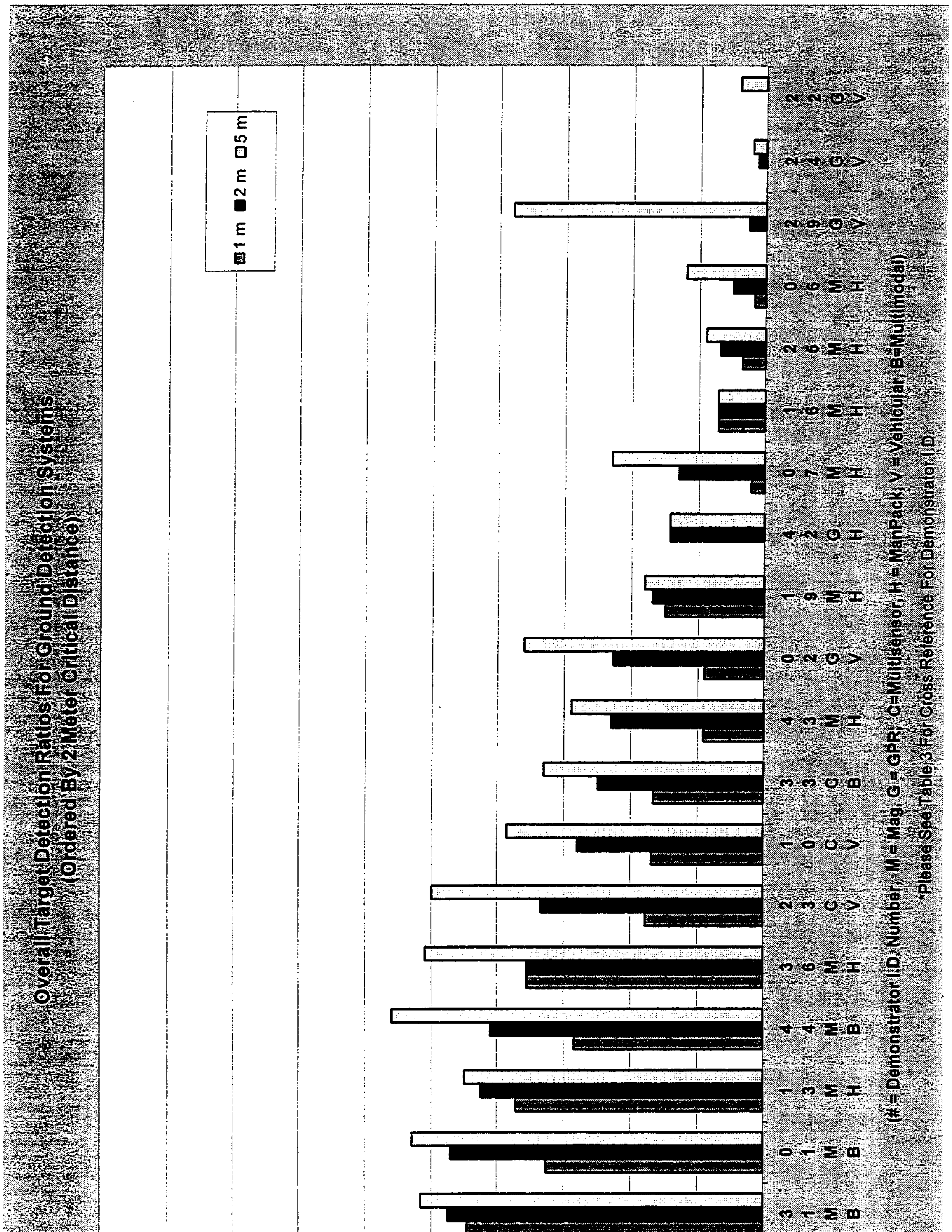
The Controlled Site Advanced Technology Program (ATD) Program was designed to determine if demonstrators would be able to detect targets, differentiate ordnance targets from non-ordnance targets, and determine their relative size, depth, class of ordnance, and orientation (azimuth and declination). Therefore, ratios used for evaluation, particularly the detection ratios (overall, ordnance, and non-ordnance) and the error ratios (false positive, false negative, and mistyped ordnance) were developed to discriminate between ordnance and non-ordnance targets. None of the demonstrators achieved detection levels to support this type of discrimination. In cases where the demonstrator only identified targets without differentiating between ordnance and non-ordnance type targets, the error ratios were no longer meaningful. While other evaluation ratios can and will be developed for future tests, the test protocols dictated the use of the present ratios, and the results presented here only address these ratios.

6.2 Overall Demonstrator Performance

6.2.1 Overall Detection Ratios - Ground. Figure 3 shows the overall detection ratio for all ground systems, ordered by their performance using the 2-m critical radius results. The sensor type and transport mode are shown on the abscissa. M designates a magnetometer, G designates a ground penetrating radar, C designates a multisensor system, H designates a handheld or man-portable platform, V represents a vehicular system (either towed or self-propelled), and B designates multimodal systems. The overall detection ratios ranged from 0 percent of all targets (ordnance and non-ordnance) to 65 percent for the 2-m critical radius case.

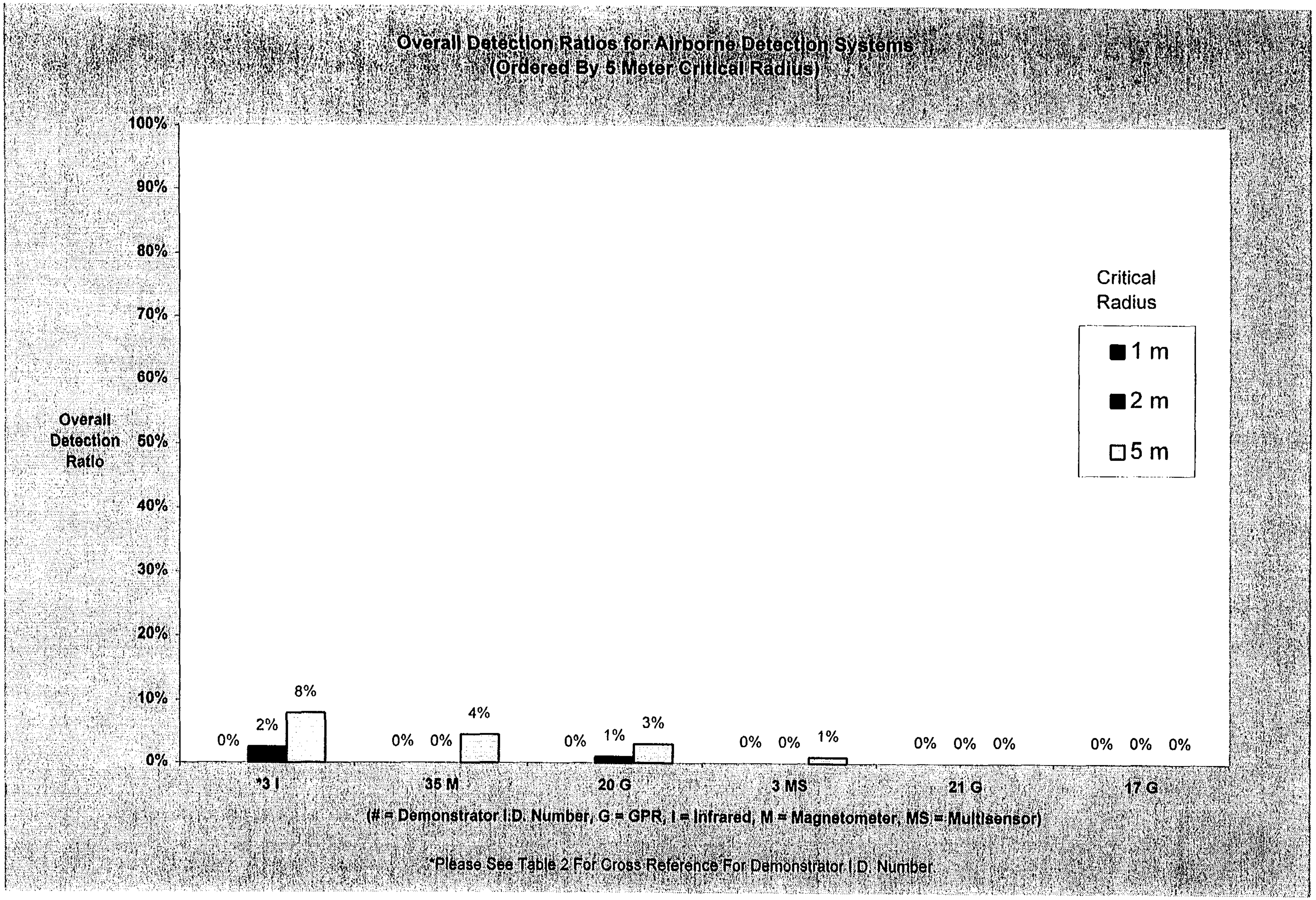
6.2.2 Overall Detection Ratios - Air. Figure 4 shows the overall detection ratio for all airborne systems in order of their performance. The 5 m critical radius results were used for ordering the performances. Results indicate that essentially no detection occurred at 1 m critical radius, a few targets were detected for two systems at 2 m, and less than 10 percent of the targets were identified for three systems at 5 m. Two systems had essentially no detection capability, and the detection capabilities for all systems were below 10 percent.

6.2.3 Area Coverage. All airborne systems except for that used by Battelle covered the entire 80-acre area in their search patterns. Only four ground systems, two of which were man-portable and two of which were



Overall Target Detection Ratios For Ground Detection Systems
(Ordered By 2 Meter Critical Distance)
1 m 2 m 5 m
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
37MV*
31MB
01MB
13MH
44MB
36MH
23CV
10CV
33CB
43MH
02GV
19MH
42GH
07MH
16MH
26MH
06MH
29GV
24GV
22GV
(# = Demonstrator I.D Number, M = Mag, G = GPR, C=Multisensor, H = ManPack, V = Vehicular, B=Multimodal)
*Please See Table 3 For Cross Reference For Demonstrator I.D

Figure 3



Overall Detection Ratios for Airborne Detection Systems
(Ordered By 5 Meter Critical Radius)
Overall Detection Ratio
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Critical Radius
1 m
2 m
5 m
0% 2% 8%
0% 0% 4%
0% 1% 3%
0% 0% 1%
0% 0% 0%
0% 0% 0%
*3 I
35 M
20 G
3 MS
21 G
17 G
(# = Demonstrator I.D. Number, G = GPR, I = Infrared, M = Magnetometer, MS = Multisensor)
*Please See Table 2 For Cross Reference For Demonstrator I.D. Number

Figure 4

vehicular/towed, covered the entire 40-acre area. Two systems covered less than 10 percent of the area. Figure 5 is a bar chart representing what percent of the 40 acres was covered by each demonstrator. The bar chart is ordered by the percentage of the area surveyed in the allotted demonstration period.

6.2.4 **Performance by Sensor and Platform Groups.** The 26 detection, location, and identification demonstrators were grouped by sensor type and platform, and the detection ratios and area covered determined for each group. The groups and results are shown in table 6. The first column presents the sensor type and the second column shows the transport mode. The results reported represent the 5-m critical radius for airborne systems and the 2-m critical radius for ground systems. Some groups consist of only one system, and the detection ratios and coverage are shown for that system. The mean detection ratios and coverage are shown for the remaining groups. The highest detection ratios were for a single vehicular/towed magnetometer (65 and 59 percent for the overall and ordnance detection ratios, respectively). Ground multimodal magnetometers had the next highest detection ratios, with an average of 40 percent for both ratios for a group of four systems. A system may appear more than once, once in it own group and again for "All Modes".

In figure 6 several of the categories in table 6 were combined to show a bar chart of six groups for the overall detection ratio and the area coverage. These are airborne-GPR; airborne-other (combining the infrared, magnetometer, and multi-sensor systems into a single group); ground-GPR; ground-magnetometer; ground-multi-sensor; and ground-multimodal magnetometer. The highest detection ratio is for the ground-multimodal magnetometer at 40 percent, followed by Ground-Magnetometers at 33 percent.

Figure 7 presents the target type detection ratio for small, medium, large, single, and multiple target types for five groups. The ground-based multi-sensor systems had the best performance.

Figure 8 shows the classification detection ratios for bombs, mortars, projectiles, mines, and clutter for the same groups of systems as above. The ground-based multi-sensor systems had the best performance.

Because many demonstrators did not have valid false positive, false negative, and mistyped ordnance ratios, valid statistics for groups of demonstrators could not be obtained.

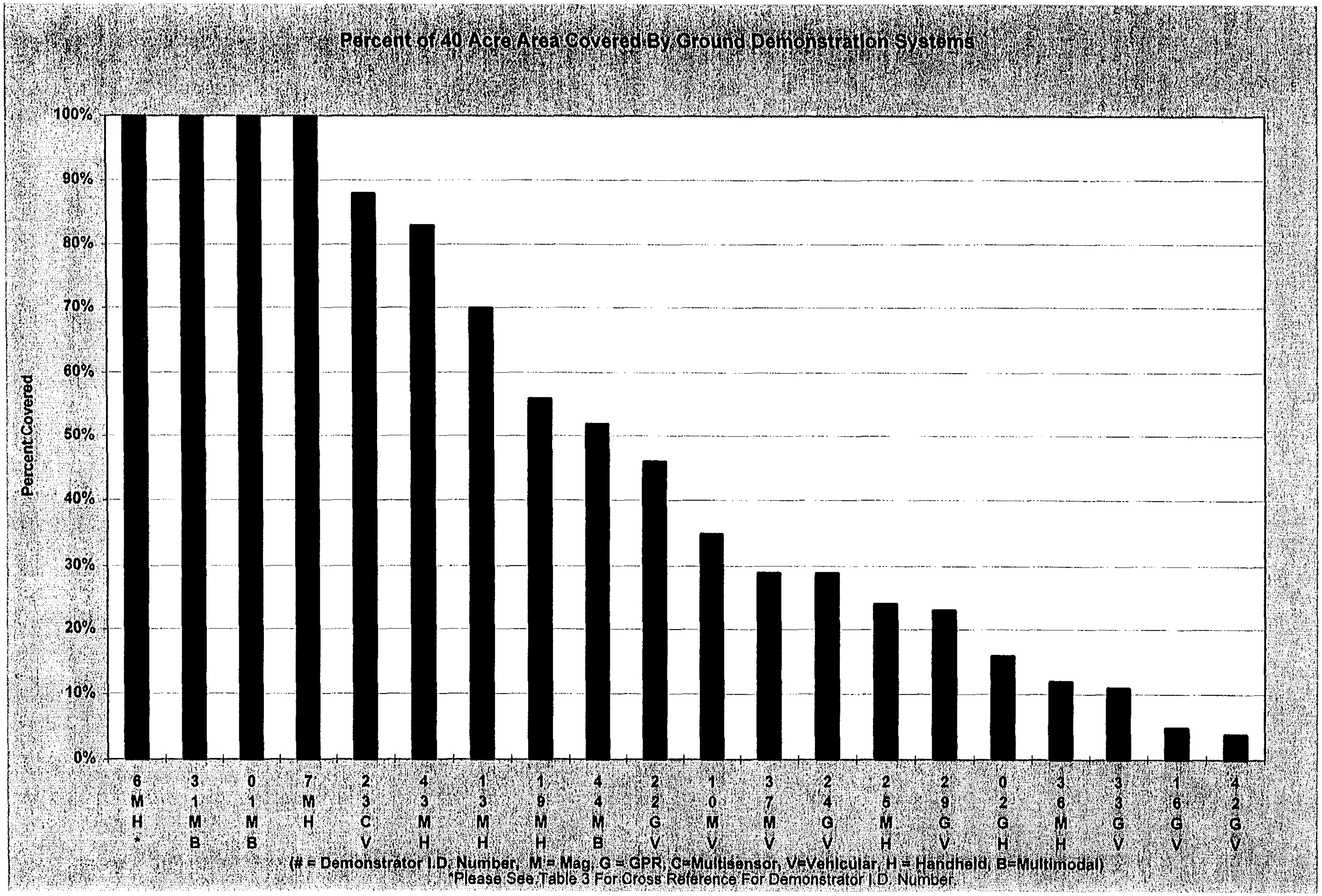

Percent of 40 Acre Area Covered By Ground Demonstration Systems
Percent Covered
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
6 M H *
3 1 M B
0 1 M B
7 M H
2 3 C V
4 3 M H
1 3 M H
1 9 M H
4 4 M B
2 2 G V
1 0 M V
3 7 M V
2 4 G V
2 5 M H
2 9 G V
0 2 G H
3 6 M H
3 3 G V
1 6 G V
4 2 G V
(# = Demonstrator I.D. Number, M = Mag, G = GPR, C=Multisensor, V=Vehicular, H = Handheld, B=Multimodal)
*Please See Table 3 For Cross Reference For Demonstrator I.D. Number.

Figure 5

Table 6

Detection Ratios and Area Coverage Performance by Platform And Sensor Types by Classes

Sensor Type	Transport Modes	Overall Detection Ratio	Ordnance Detection Ratio	Search Coverage	Number In Class
GPR	Air	1%	1%	79%	3
Infrared	Air	8%	7%	100%	1
Magnetometer	Air	4%	4%	100%	1
Multi-sensor	Air	1%	1%	100%	1
Multi-sensor	Ground - Multimodal	24%	25%	71%	3
Magnetometer	Ground - All Modes	33%	30%	69%	11
Magnetometer	Ground - Multimodal	40%	40%	95%	4
Magnetometer	Ground - Handheld *	23%	20%	64%	7
Magnetometer	Ground - Vehicular	65%	59%	29%	1
GPR	Ground - All Modes	8%	9%	21%	6
GPR	Ground - Vehicular	7%	7%	24%	5
GPR	Ground - Handheld*	14%	20%	4%	1

* Handheld or Man-Towed

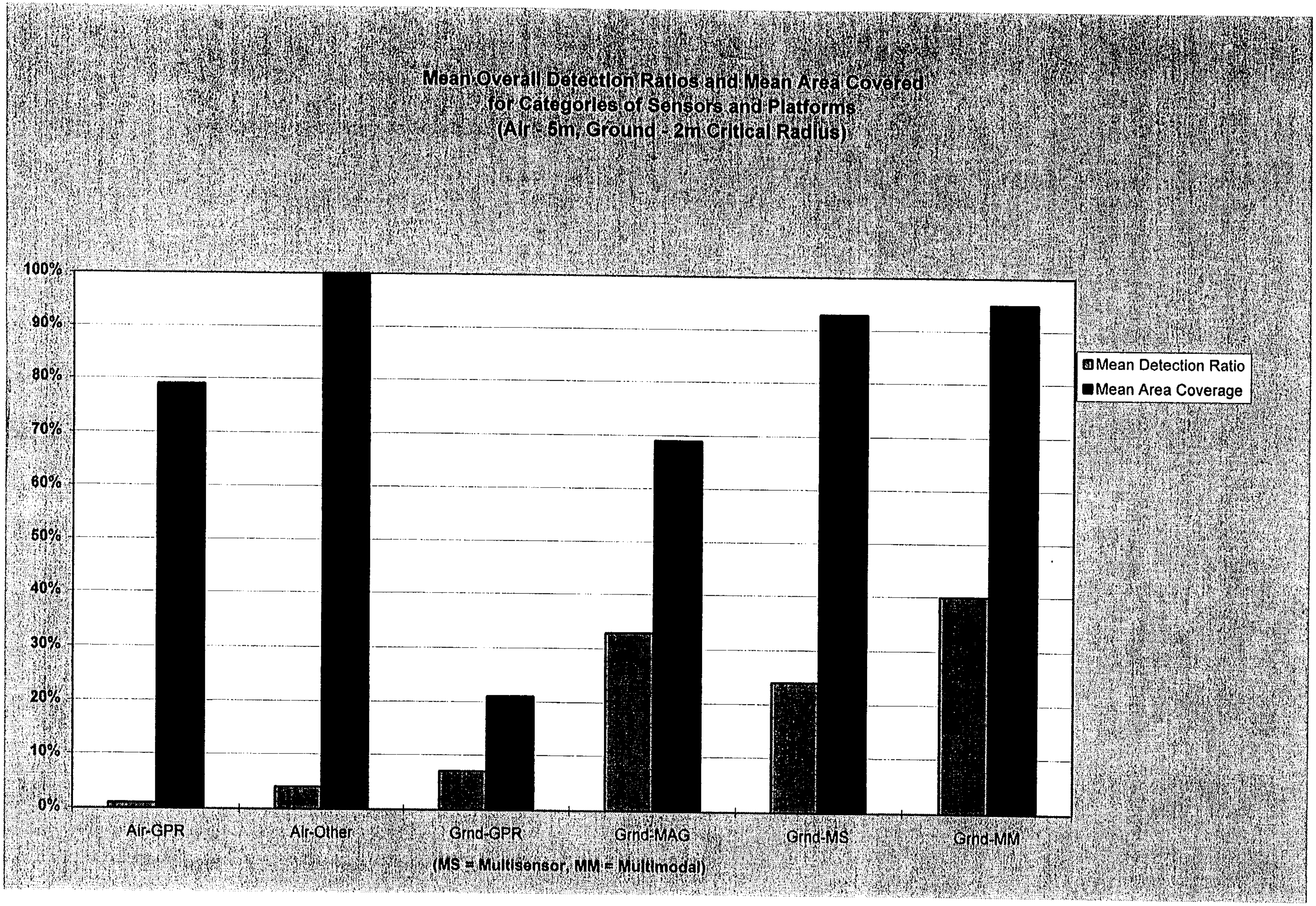
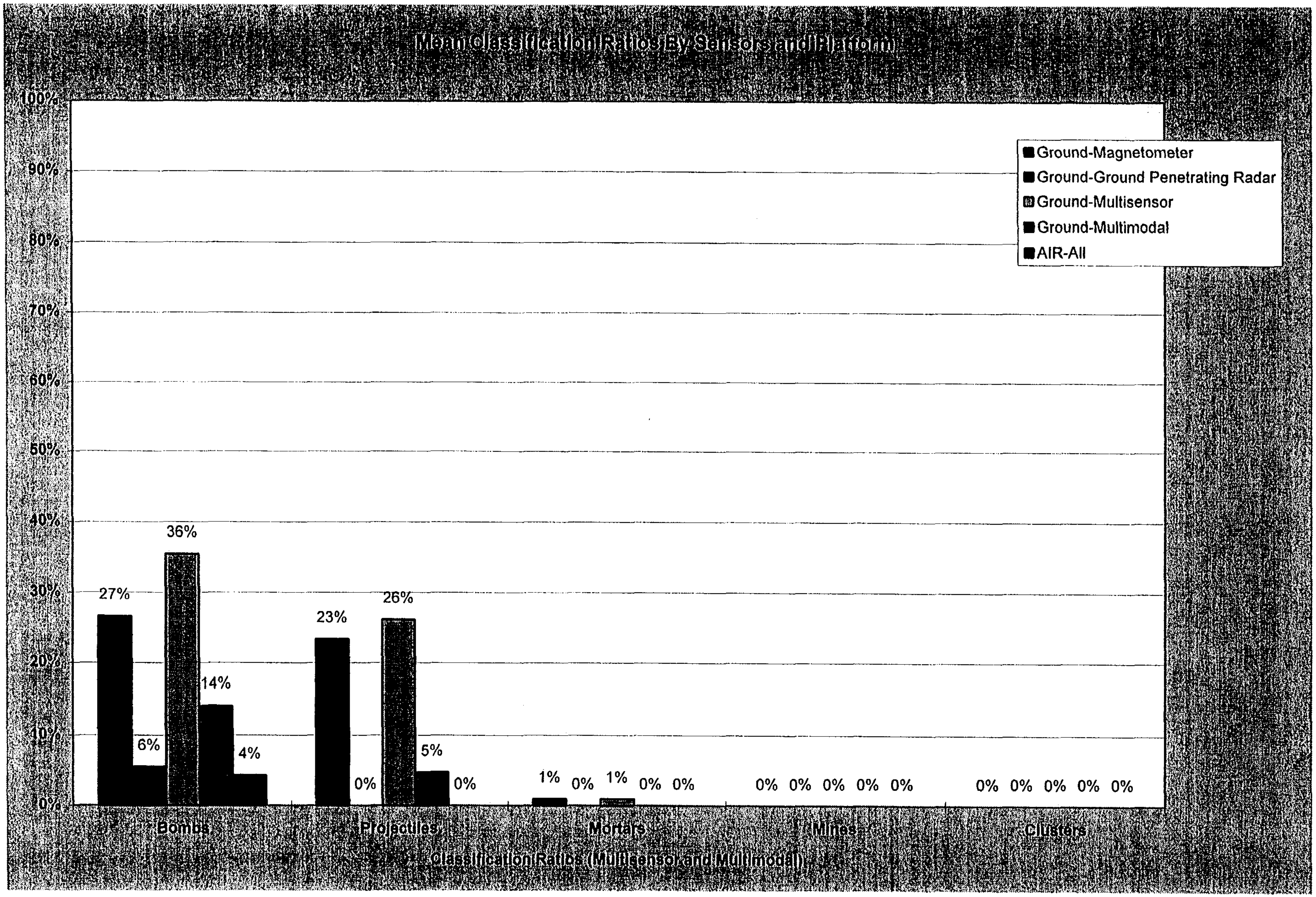

Mean Overall Detection Ratios and Mean Area Covered
for Categories of Sensors and Platforms
(Air - 5m, Ground - 2m Critical Radius)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Air-GPR
Air-Other
Grnd-GPR
Grnd-MAG
Grnd-MS
Grnd-MM
(MS = Multisensor, MM = Multimodal)
Mean Detection Ratio
Mean Area Coverage

Figure 6


Ground-Magnetometer
Ground-Ground Penetrating Radar
Ground-Multisensor
Ground-Multimodal
Air-All
20%
7%
2%
42%
14%
57%
2%
4%
51%
34%
10%
40%
35%
2%
4%
15%
3%

Figure 7



Mean Classification Ratios By Sensors and Platform
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ground-Magnetometer
Ground-Ground Penetrating Radar
Ground-Multisensor
Ground-Multimodal
AIR-All
27%
6%
36%
14%
4%
23%
0%
26%
5%
0%
1%
0%
1%
0%
0%
0% 0% 0% 0% 0%
0% 0% 0% 0% 0%
Bombs
Projectiles
Mortars
Mines
Clusters
Classification Ratios (Multisensor and Multimodal)

Figure 8

6.3 Overall Remediation System Performance

Three robotic remediation systems were demonstrated. Of the 21 retrieval attempts made, 18 targets were satisfactorily retrieved. The total time for remediation (including accurate positioning, setting up, excavating, and retrieving) was often measured in hours rather than minutes (see table 5 on page 37). Robotic remediation equipment travels between 2 and 3 miles per hour on the average. Position verification and set up for excavation time varied from 15 to 40 minutes. Depth perception via remote cameras was poor on two of the demonstrated systems causing frequent delays to check the depth attained. The average number of ordnance items the demonstrators could remediate was 5 per day, taking into account set up, travel to target coordinates, and retrieval.

The ability to retrieve live ordnance safely and accurately was, judging by these demonstrations, inversely proportional to the size of the excavator. The cost and size of these systems is therefore a major factor to be considered - the larger systems may be able to sustain unintentional explosions, the more costly systems may avoid such explosions.

Overall, the demonstrations confirmed the practicality of autonomous remediation if location and visual monitoring systems are fully integrated into the excavating platforms. The demonstrations also indicated that remediation with current state-of-the-art robotic technology is still a slow process.

7 Conclusions

The data provided in this report establish a performance baseline for UXO detection, identification, location, and remediation technology. The demonstrations completed as part of this program permit the Government to characterize the state-of-the-art technologies, and to identify the capabilities and limitations of a broad spectrum of technologies operated in a controlled environment.

The results of this program indicate that additional efforts are necessary to improve the state-of-the-art in sensor, data analysis, and robotic excavation technology. The ordnance detection sensors and data analysis systems demonstrated at JPG were generally unable to distinguish ordnance targets from the non-ordnance debris. It is just as time-consuming for robotic systems to excavate non-ordnance as ordnance. Technology advancements are needed in order to better detect and classify targets, and to excavate targets more efficiently. Future controlled-site demonstrations at JPG will allow the Government to measure these technology improvements.

The system performance data contained in this report are unique to JPG. System performance will vary based on the site environment and UXO contamination conditions. The reader is cautioned against using the data to derive specific performance requirements for actual UXO remediation operations.

References

1 *Area Report*, PRC Inc., Contract No. N00600-88-D-3717/FG-3S/CDRL Item A011.

2 *Cleanup and Reuse Options: U.S. Army Jefferson Proving Ground*, Mason & Hanger-Silas Mason Co., Inc., draft report, April 1992.

3 *Contaminated Area Clearance and Land-Use Alternatives*, Engineer Studies Group, Office of the Chief of Engineer, Department of the Army, 1975.

4 *Range Clearance Technology Assessment Report*, Naval Explosive Ordnance Technology Center, Indian Head, Maryland, Revision 1, 1990.

5 *Area Layout Plan*, PRC Inc., Contract No. N00600-88-D-3717/FG-3S/CDRL Item A010.

6 *Technology Selection Evaluation Plan*, PRC Inc., Contract No. N00600-88-D-3717/FG-3S/CDRL Item A009.

7 *User's Manual for the JPG Technology Assessment Database*, Automation Research Systems, Ltd., November 10, 1994

8 *Design Document for the Target Matching Algorithm*, Automation Research Systems, Ltd., November 10, 1994

9 *Demonstrator Work Plan for the UXO Detection, Identification, and Remediation Advanced Technology Demonstration at the Jefferson Proving Ground*, PRC Inc., Contract No. N00600-88-D-3717/FG-3S

APPENDIX

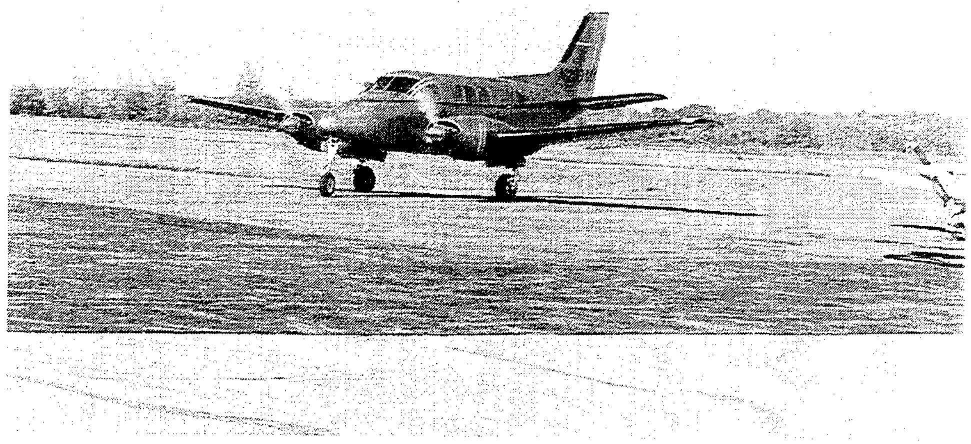
SYSTEMS AND TECHNOLOGIES DEMONSTRATED

DESCRIPTIONS AND RESULTS

Color Key for Tabs

Color Code	**Technology Demonstrated**
Red	Ground Penetrating Radar (GPR)
Yellow	Magnetometer
Green	Infrared (IR)
Black	Multi-sensor - GPR/IR
Dark Blue	Multi-sensor - GPR/Magnetometer
Light Blue	Magnetometer/Software
Brown	Remediation

Index of Demonstrators



SRI International (Fixed Wing)

System Description and Operation. SRI used an airborne GPR for the detection and location of UXO. The platform is a Beech Queen Air aircraft with a bistatic antenna configuration with the transmitting array under the left wing and the receiving array under the right. Either horizontal-horizontal or vertical-vertical polarization is possible. The GPR uses synthetic aperture processing, enabling integration of hundreds of pulse returns. The radar produces a high resolution image strip with a coverage rate of 50 sq km/hr. The data collected is processed into images of the total area at a 1-m by 1-m resolution, and of selected areas at 0.5-m by 0.5-m resolution. A differential GPS (DGPS) is linked to the data acquisition system to recover position information to within a few centimeters. This information is required for proper processing when the aircraft track deviates from a straight line by more that 15 cm. It is also used to reference the target locations to the origin of the site grid. DGPS processing requires an on-board GPS receiver and a stationary GPS receiver located near the test site. Data is processed into two-dimensional images. Regions of bright reflections are identified as possible UXO sites. These images and candidate targets are then interpreted by being compared to overhead photographs of the area to correlate radar features with surface features. Depth information can be obtained by generating correlated image pairs of regions with suspected buried targets, and performing parallax processing.

Survey/Operations Summary. The survey was conducted 7 through 15 May 1994 and covered 80 acres. Air turbulence precluded operations from late morning to late afternoon.

Support Equipment. None

System Limitations. The system requires smooth air to function properly. Wet ground conditions adversely affect the GPR.

Problems Affecting Survey. No significant problems.

SRI INTERNATIONAL (Fixed Wing)

Air | Site: 80 Acre

System Description

Address:	333 Ravenswood Avenue Menlo Park, California 94025 (USA)
Demonstration Dates	5/7/94 to 5/15/94
System Name:	SRI FOLPEN I
System Type:	Airborne
Sensor Name:	SRI
Sensor Type:	Ground Penetrating Radar
Range (claimed):	Btw 2 feet and 4.99 feet
Navigation System:	Ashtech
Navigation Type:	Differential GPS
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	100%

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	0%	1%	3%
Ordnance	1%	1%	2%
Non-Ordnance	0%	0%	8%

	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	*	*	100%
False Negative	99%	98%	97%
Mistyped	0%	0%	0%

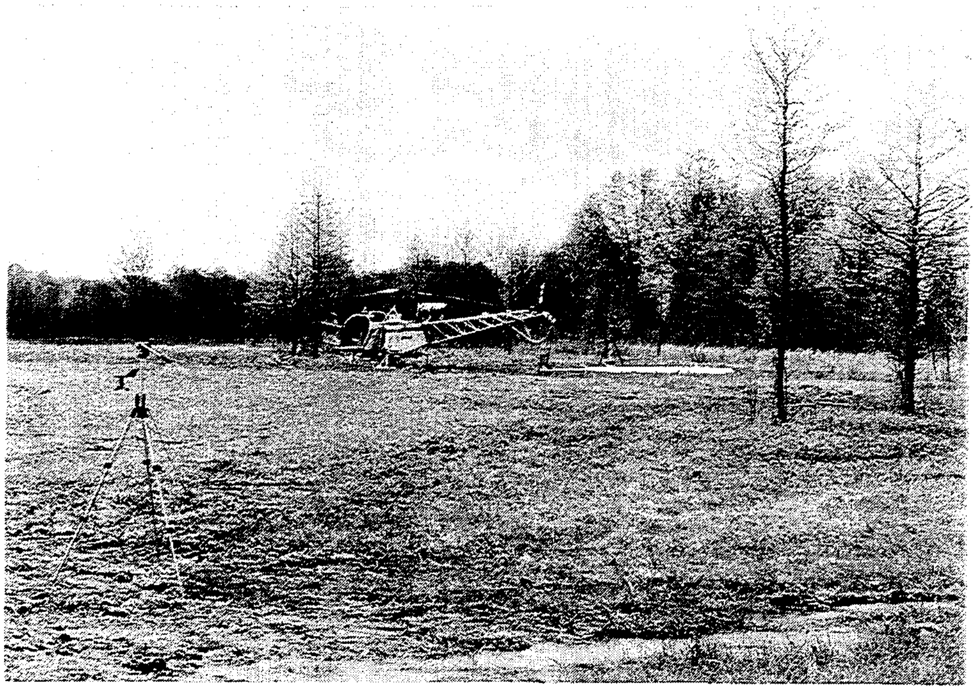
	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	1%	1%	2%
Multiple Targets	0%	0%	0%
Small Targets	0%	1%	2%
Medium Targets	0%	0%	2%
Large Targets	3%	3%	8%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	1.03	1.40	3.14
Standard Deviation	-	0.52	1.40

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	5.37	2.69	1.56
Standard Deviation	-	3.80	2.34

* All Targets Declared Indiscriminately As Ordnance



Geonex Aerodat, Inc.

System Description and Operation. The Geonex system uses magnetics, a vertical magnetic gradiometer, and multifrequency electromagnetics. The system consists of a 6-m long, 90-kg Kevlar tube that is towed 30-m below a helicopter. A wideband EM transmitter and receiver are housed within the tube. The two antennas are 5-m apart and are oriented in a horizontal coplanar configuration. The multifrequency capability allows detection at several depths of penetration. The magnetics system consists of two high sensitivity cesium vapor magnetometers, one mounted vertically at each end of the tube. Each measures the total magnetic field; the difference between the two fields is the vertical magnetic gradient. Also in the tube are the position and attitude sensors. Position is measured by a DGPS that provides navigation and sensor positioning with sub-meter accuracy. Laser, radar, and barometric altimeters measure sensor and helicopter height; pitch and roll sensors monitor the attitude of the tube. Sensor data are sampled 10 to 20 times per second and are recorded in both analog and digital formats on-board the helicopter. Ground based operations include a base station magnetometer to monitor diurnal changes in the earth's magnetic field, and a base station GPS to provide real-time differential corrections to navigation and positioning data.

Survey/Operations Summary. The survey was conducted 23 April through 1 May 1994, and covered 80 acres. Bad weather and equipment failures caused over 31 hours of downtime.

Support Equipment. One pickup truck.

System Limitations. Severe weather prohibits flight. Visual ground references are essential for safe flight. The towed sensor is not steerable; crosswinds cause skewed data.

Problems Affecting Survey. The system's DGPS was down; ground personnel marked survey lanes. The towed sensor developed a pendulum effect in strong winds and was difficult to manage. Severe weather grounded the platform.

GEONEX AERODAT, Inc.

Air

Site: 80 Acre

System Description

Address:	3883 Nashua Drive Mississauga, Ontario L4V 1R3 Canada
Demonstration Dates	4/23/94 to 5/1/94
System Name:	Kingfisher
System Type:	Airborne
Sensor Name:	Scintrex
Sensor Type:	Magnetometer; Electromagnetic
Range (claimed):	More than 25 ft
Navigation System:	Ashtech P-12
Navigation Type:	Differential GPS
Data Proc. Hardware:	Mainframe
Data Proc. Method:	Gradient Data Difference
Area Covered	100%

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	0%	0%	4%
Ordnance	0%	0%	4%
Non-Ordnance	0%	0%	8%

	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	*	*	100%
False Negative	100%	100%	95%
Mistyped	*	*	0%

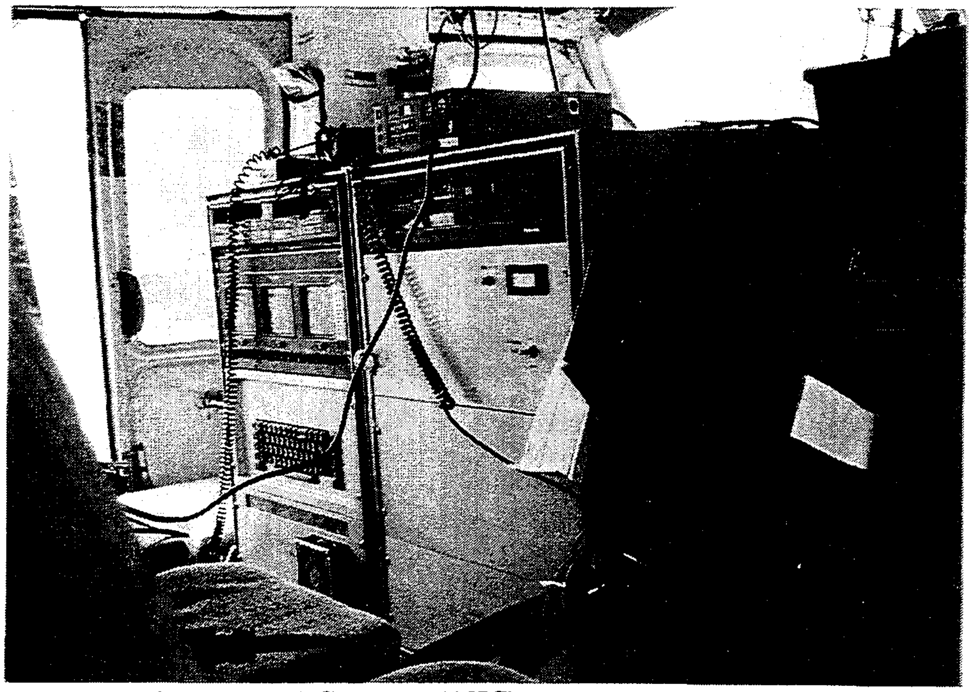
	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	0%	0%	4%
Multiple Targets	0%	0%	0%
Small Targets	0%	0%	1%
Medium Targets	0%	0%	2%
Large Targets	0%	0%	18%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	26%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	3.15
Standard Deviation	-	-	0.97

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

* All Targets Declared Indiscriminately As Ordnance



Airborne Environmental Surveys (AES)

System Description and Operation. The system uses two frequency-modulated continuous wave chirped radars. The primary system has a center frequency of 503 Megahertz (MHz) and a bandwidth of 500 MHz. The secondary system has a center frequency of 3 Gigahertz (GHz) and a bandwidth of 2 GHz. A FLIR Industries 2000F infrared imaging system is also carried to enhance detection capabilities. A DGPS is used for accurate positional information. The system uses a bistatic, polarized, helical antenna array. A series of parallel tracks is flown to obtain target data. Typical precision is a circular error of 5-m or less. Analog radar echoes are received and converted to digital data on-board the helicopter and are recorded on standard VHS video tape. Simultaneously, Fast Fourier Transform algorithms are employed in the on-board processor to display real-time radar imagery. The digitized data collected can be transferred directly to an IBM-compatible computer where the data can be viewed and analyzed. Entire flight lines or selected portions can be viewed. All or portions of adjacent flight lines can also be stacked and viewed simultaneously. Two-dimensional plan-view plots of the survey area are produced to show all detected targets. Accompanying the plot is an Echo Response Log that gives depth, classification, and position of each detected target.

Survey/Operations Summary. The survey was conducted 11 through 19 June 1994, and covered 80 acres. Helicopter mechanical problems caused over 20 hours downtime.

Support Equipment. None

System Limitations. Sensor limitations based on site geology and hydrology.

Problems Affecting Survey. No significant problems.

AIRBORNE ENVIRONMENTAL SURVEYS

Air

Site: 80 Acre

System Description

Address:	3130 Skyway Drive #108 Santa Maria, California 923455 (USA)
Demonstration Dates	6/11/94 to 6/19/94
System Name:	EMS-5
System Type:	Airborne
Sensor Name:	EMS-20
Sensor Type:	Ground Penetrating Radar
Range (claimed):	More than 25 ft
Navigation System:	Trimble
Navigation Type:	Global Positioning System
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	100%

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	0%	0%	1%
Ordnance	0%	1%	1%
Non-Ordnance	0%	0%	0%

	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	*	*	*
False Negative	100%	97%	95%
Mistyped	*	0%	0%

	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	0%	1%	1%
Multiple Targets	0%	0%	17%
Small Targets	0%	1%	1%
Medium Targets	0%	0%	0%
Large Targets	0%	0%	3%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	1.83	2.34
Standard Deviation	-	-	0.73

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	0.29	0.28
Standard Deviation	-	-	0.02

* All Targets Declared Indiscriminately As Ordnance

SRI International (Rotary Wing)

System Description and Operation. The system uses an ultra-wideband GPR operating in the VHF and low UHF bands. The GPR uses a bistatic antenna configuration with the transmitting antenna on the right side of the aircraft and the receiving antenna on the left. The radar is normally operated in the line profiling mode, producing real-time, false-color displays. Digitized GPR data is recorded on optical disk for post-mission review and/or migration processing. GPS position is also recorded twice per second. GPR and GPS data are plotted in real time on the radar display, giving the operator a plan view of the aircraft track and search pattern. In the line profiling mode, the operator marks likely targets with a hand-held switch. The GPS determined coordinates of the mark and the operator's assessment of the target are recorded and superimposed on an area map generated and printed in the air for handoff to search crews on the ground. The survey was flown in a grid pattern in 50-m offsets along preselected magnetic headings. It was then repeated with headings rotated 90 degrees. This grid pattern was repeated for several system configurations optimized for particular penetration regimes. Post-flight analysis provided a list of targets for focused inspection on additional flights using smaller offsets (10-m).

Survey/Operations Summary. Survey was conducted 18 through 26 June 1994 and covered 80 acres.

Support Equipment. None

System Limitations. Sensor limitations due to soil conditions, maximum depth 10-m in dry sandy soil.

Problems Affecting Survey. Weather problems, DGPS failure.

SRI INTERNATIONAL (Rotary Wing)

Air | Site: 80 Acre

System Description

Address:	333 Ravenswood Avenue Menlo Park, California 94025 (USA)
Demonstration Dates	6/18/94 to 6/26/94
System Name:	HELPEN3
System Type:	Airborne
Sensor Name:	SRI International
Sensor Type:	Ground Penetrating Radar
Range (claimed):	More than 25 ft
Navigation System:	Ashtech
Navigation Type:	Differential GPS
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	100%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	0%	0%	0%
Ordnance	0%	0%	0%
Non-Ordnance	0%	0%	0%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	*	*	*
False Negative	100%	100%	100%
Mistyped	*	*	*

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	0%	0%	0%
Multiple Targets	0%	0%	0%
Small Targets	0%	0%	0%
Medium Targets	0%	0%	0%
Large Targets	0%	0%	0%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

* All Targets Declared Indiscriminately As Ordnance

Oilton, Inc.

System Description and Operation. The Advanced Infrared Detection System (AIRDS) uses a FLIR 2000AB, a two field-of-view (28 x 15 degree and 7 x 3.25 degree) spherical imager mounted in an aerodynamic precision pointing system on the helicopter. All system controls were adjusted with a hand-held system controller. A complete data monitoring system was also installed for real time-viewing and adjustments. All image data was recorded continuously on standard magnetic tape, which can be further reduced, frame by frame, using the AIRDS image processing system. A separate Charged Coupled Device (CCD) camera was mounted with the IR camera and linked to a second video recorder to record simultaneous visual imagery for frame-by-frame visual correlation during the documentation process. The AIRDS Image Data Logger (IDL) is a mobile image data recorder with video digitization capability and a continuous communication link with a GPS receiver for encoding GPS positioning in the video stream. During the IR imaging process, a thermographer can digitally record thermal data when an anomaly observation occurs. By hitting a button on the IDL, a frame of choice could be sampled from the live video data stream and stored for future processing. This feature was used to locate landmarks during the ground truth phase of the program for correlation with target images during the analysis phase.

Survey/Operations Summary. Survey was conducted 10 through 18 September 1994, and covered 80 acres.

Support Equipment. One minivan.

System Limitations. Sensor limitations due to soil conditions.

Problems Affecting Survey. No significant problems.

OILTON, Inc.

Air

Site: 80 Acre

System Description

Address:	1821 University Avenue St. Paul, Minnesota 55104 (USA)
Demonstration Dates	9/10/94 to 9/18/94
System Name:	AIRDS
System Type:	Airborne
Sensor Name:	FLIR
Sensor Type:	Infrared
Range (claimed):	Btw 5 ft and 9.99 ft
Navigation System:	AIRDS NAV.
Navigation Type:	Map Correlation; Visual References; Position Documentation
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Image Processing and Pattern Recognition
Area Covered	*100%*

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	0%	2%	8%
Ordnance	1%	3%	7%
Non-Ordnance	0%	0%	13%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	*	*	0%
False Negative	*	*	*
Mistyped	100%	100%	100%

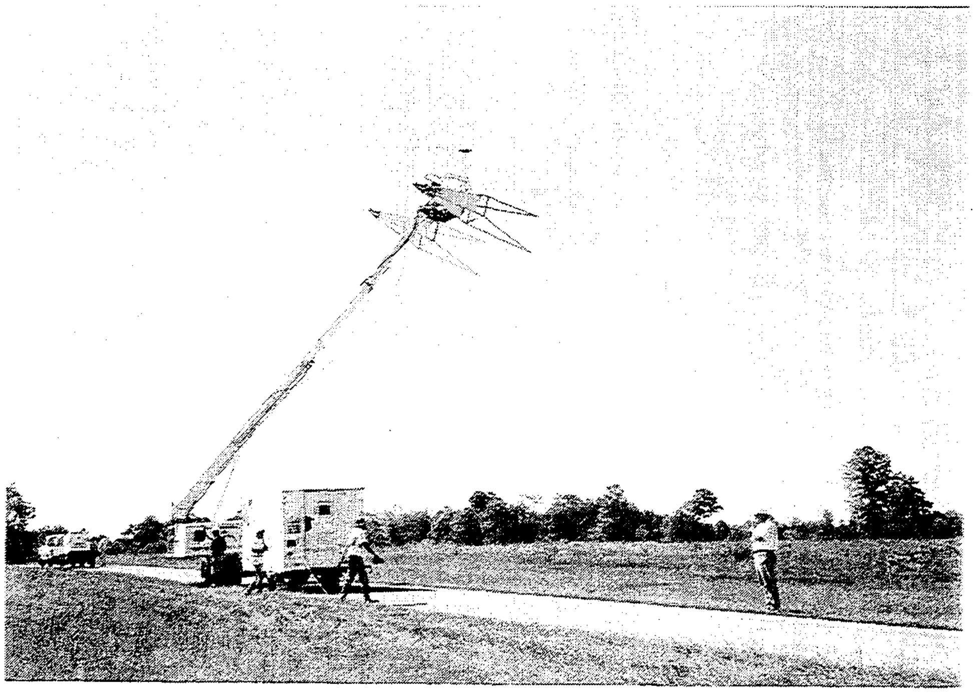
Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	1%	3%	8%
Multiple Targets	0%	0%	0%
Small Targets	1%	4%	9%
Medium Targets	0%	2%	7%
Large Targets	0%	0%	0%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.18	1.34	2.68
Standard Deviation	-	0.77	1.11

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

* Ordnance or Non-Ordnance Not Declared



Battelle (Airborne)

System Description and Operation. Battelle demonstrated a GPR developed originally for detecting plastic utility pipes and for locating near-surface land mines. This system has been modified to detect buried UXO. Two antenna were bolted to an aerial platform and elevated above the ground. IBM compatible computers and a power supply were located on the ground. These computers provided limited real-time feedback of the recorded data. A Trimble GPS navigation system was used. A superheterodyne receiver processed the analog data into digital format. The data stream was routed to the recording computer where results were displayed on a color monitor. Further data processing was conducted offsite at Ohio State University (OSU).

Survey Operations Summary. Survey was conducted 17 through 25 September 1994, and covered 27 acres.

Support equipment. A large Ryder van, a mobile 30 kw generator towed by a pickup truck.

System Limitations. Survey rate was between .25 and .33 mph on a paved road.

Problems Affecting Survey. System was designed for an airborne platform, but was mounted on an aerial platform for this demonstration.

BATTELLE (Airborne)

Air — Site: 80 Acre

System Description

Address:	505 King Avenue Columbus, Ohio 43201 (USA)
Demonstration Dates	9/17/94 to 9/25/94
System Name:	Big Ear Step-Chirped Radar
System Type:	Airborne
Sensor Name:	Custom
Sensor Type:	Ground Penetrating Radar
Range (claimed):	Btw 1 foot and 1.99 ft
Navigation System:	Trimble
Navigation Type:	Differential GPS; Tick-Wheel
Data Proc. Hardware:	UNIX Workstations
Data Proc. Method:	Data Transformation; Waterfall Plots; SAR Processing
Area Covered	36%

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	0%	0%	0%
Ordnance	0%	0%	0%
Non-Ordnance	0%	0%	0%

	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	*	*	*
False Negative	100%	100%	100%
Mistyped	*	*	*

	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	0%	0%	0%
Multiple Targets	0%	0%	0%
Small Targets	0%	0%	0%
Medium Targets	0%	0%	0%
Large Targets	0%	0%	0%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

* All Targets Declared Indiscriminately As Ordnance

Chemrad (GSM-19)

System Description and Operation. The Chemrad system uses the GSM-19 Overhauser Memory Magnetometer for locating, mapping, and identifying subsurface UXO, and the UltraSonic Ranging and Data System (USRADS) to provide high resolution tracking (to ± 6 inches) and high density sampling. The GSM-19 is used to measure magnetic field anomalies as an indication of buried ferrous objects. The outputs from the GSM-19 are recorded each second by the USRADS and are stored for post-processing. A reference GSM-19 is positioned in an inactive magnetic area for use in correcting the field measurement for diurnal magnetic field variations. The USRADS data arrays are stored on-line in the field computer. A real-time display of the data enhanced track map is shown on the computer display while the survey is in progress. USRADS locates the surveyor once per second using the acoustic travel times from an ultrasonic transmitter carried on a backpack to transducers mounted on tripods. These travel times are reported to the field computer via Radio Frequency (RF) transmissions. Simultaneously, a radio transmitter on the backpack sends the survey detector readings to the field computer. The data collected is plotted as a color-coded track map and is further processed into a color contour map showing the location of magnetic anomalies in the X-Y plane. Anomalies noted in the color contour map are logged according to location and magnitude of the magnetic field disturbance.

Survey/Operations Summary. Survey was conducted 7 through 15 May 1994, and covered 40 acres.

Support Equipment. None

System Limitations. The USRADS navigation system is susceptible to acoustic interference.

Problems Affecting Survey. No significant problems.

CHEMRAD (GSM-19)

Ground **Site:** 40 Acre

System Description

Address:	1055 Commerce Park D Oak Ridge, Tennessee 37830 (USA)
Demonstration Dates	5/7/94 to 5/15/94
System Name:	USRADS
System Type:	Man-Portable
Sensor Name:	GEM (GSM-19)
Sensor Type:	Magnetometer
Range (claimed):	Btw 10 ft and 14.99 ft
Navigation System:	USRADS
Navigation Type:	Acoustic Positioning System
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	100%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	2%	5%	12%
Ordnance	1%	4%	12%
Non-Ordnance	4%	7%	12%

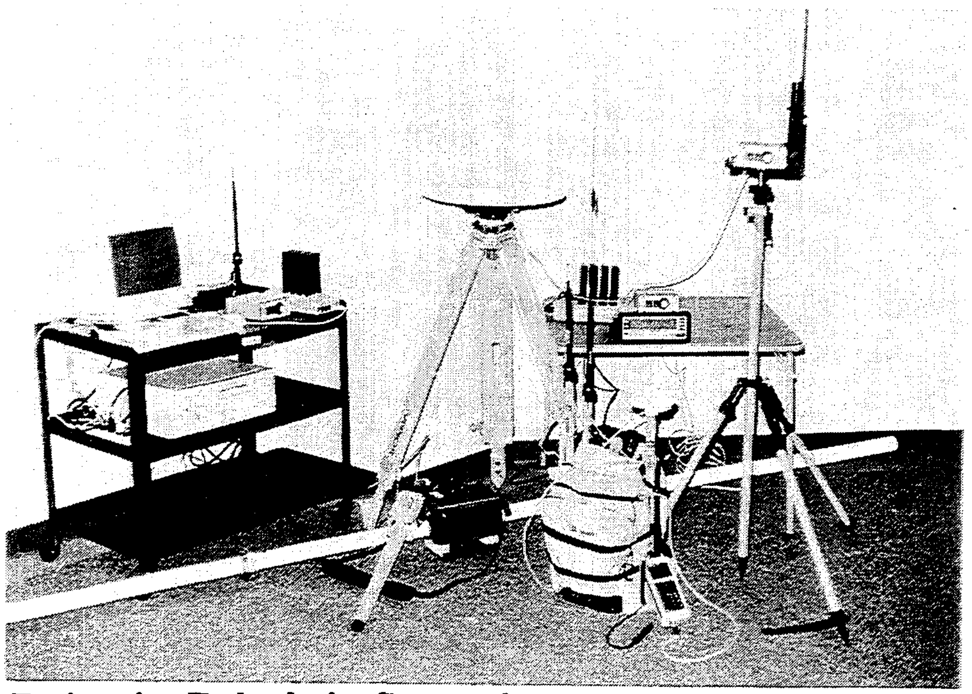
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	100%	97%	93%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	1%	4%	12%
Multiple Targets	0%	0%	11%
Small Targets	0%	3%	9%
Medium Targets	0%	6%	16%
Large Targets	6%	7%	13%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.89	1.69	2.98
Standard Deviation	0.28	0.45	1.14

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.75	0.56	0.55
Standard Deviation	0.72	0.59	0.45



Arete Engineering Technologies Corporation

System Description and Operation. Arete's GeoDAPS detection system consists of the following four subsystems: DGPS navigation, programmable sensor interface, real-time data acquisition/display, and proprietary software. Two standard man-portable geophysical instruments were used, an active electromagnetic sensor (Geonics EM31) and a passive magnetic gradient sensor (Schonstedt GA72CV). In addition, the GeoDAPS was used to record the survey data and place it in absolute coordinates. GeoDAPS uses DGPS to determine the precise location of the survey data and uses calibration data to output sensor information in physical units. Data are recorded internally in the GeoDAPS operator's backpack and are also telemetered to a base station PC for real-time display and monitoring. GeoDAPS provides processing of high resolution, calibrated electromagnetic sensor data, along with information about the signal to estimate the characteristics of subsurface objects. An essential element of the processing is the use of both active and passive electromagnetic sensors. Adding active sensing to the passive provides added degrees of freedom for estimating object parameters and characterization of non-magnetic objects. The system provides detailed characterization information including three-dimensional position, axis, orientation, and size of all objects found within the test area.

Survey/Operations Summary. Survey was conducted 14 through 22 May 1994, and covered 22 acres.

Support Equipment. Two full-sized vans.

System Limitations. The system is limited by clutter from nearby objects or heavy rain that might cause standing water, thereby increasing environmental noise levels.

Problems Affecting Survey. Demonstrator personnel were unprepared for the rigors of a field demonstration.

ARETE' ENGINEERING TECHNOLOGIES CORP.

Ground — Site: 40 Acre

System Description

Address:	1725 Jefferson Davis Highway Arlington, Virginia 22202 (USA)
Demonstration Dates	5/14/94 to 5/22/94
System Name:	GeoDAPS
System Type:	Man-Portable
Sensor Name:	Geonics; Schonstedt
Sensor Type:	Induction Coil; Magnetometer
Range (claimed):	More than 25 ft
Navigation System:	Trimble
Navigation Type:	Differential GPS
Data Proc. Hardware:	UNIX Workstations
Data Proc. Method:	Combinations of the above
Area Covered	55%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	15%	17%	18%
Ordnance	15%	16%	18%
Non-Ordnance	15%	20%	20%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	89%	89%
False Negative	70%	67%	63%
Mistyped	6%	6%	5%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	16%	17%	18%
Multiple Targets	0%	0%	0%
Small Targets	4%	4%	6%
Medium Targets	31%	39%	35%
Large Targets	23%	23%	25%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	20%	20%	20%
Projectiles	22%	24%	24%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.40	0.54	1.05
Standard Deviation	0.27	0.41	1.29

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.46	0.42	0.41
Standard Deviation	0.60	0.57	0.56

Chemrad (G-822L)

System Description and Operation. This demonstration also uses the USRADS navigation system described in the Chemrad GSM-19 demonstration (see Tab 7). In conjunction with the USRADS, this demonstration used the G-822L Magnetometer. The magnetometer was interfaced directly to the USRADS so that the gradient magnetic field intensity and polarity were recorded directly in the USRADS computer at the rate of 10 samples per second. Survey results were displayed in real-time and were monitored by a member of the survey team. Adjustments in survey protocol were effected online as indicated by the data received in order to obtain the optimal spatial resolution for detection and location. Immediately after the survey of each grid, color-enhanced track map plots of the detector findings were produced so that any further investigations could be carried out before moving to the next grid. The final outputs were the color-coded track maps, color contour maps, and the underlying raw target data.

Survey/Operations Summary. Survey was conducted 14 through 22 May 1994, and covered 40 acres.

Support Equipment. A small trailer was used as a mobile data processing center.

System Limitations. The USRADS navigation system is susceptible to acoustic interference.

Problems Affecting Survey. No significant problems.

CHEMRAD (G-822L)

Ground | Site: 40 Acre

System Description

Address:	1055 Commerce Park Oak Ridge, Tennessee 37830 (USA)
Demonstration Dates	5/14/94 to 5/22/94
System Name:	USRADS w/ Cesium Vapor Magnetometer
System Type:	Man-Portable
Sensor Name:	G-822L
Sensor Type:	Magnetometer
Range (claimed):	Btw 20 ft and 24.99 ft
Navigation System:	USRADS
Navigation Type:	Acoustic Positioning System
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Image Processing and Pattern Recognition
Area Covered	100%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	16%	28%	38%
Ordnance	17%	27%	36%
Non-Ordnance	14%	30%	41%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	0%	0%	0%
False Negative	*	*	*
Mistyped	100%	100%	100%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	18%	28%	38%
Multiple Targets	0%	0%	0%
Small Targets	2%	7%	12%
Medium Targets	24%	41%	69%
Large Targets	24%	35%	34%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.87	1.21	1.91
Standard Deviation	0.31	0.47	1.20

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.75	0.68	0.68
Standard Deviation	0.58	0.63	0.62

All Targets Declared Indiscriminately As Ordnance.

Australian Defence Industries (ADI)

System Description and Operations. ADI proposed a combination of hand-held and vehicle-mounted magnetic and GPR technologies during the demonstration. The magnetic system used a total field magnetometer and computer-aided interpretation of the magnetic data to provide a list of position, depth, and approximate mass of targets. The GPR system was to be used to confirm those parameters. However, after evaluating the conditions at the test site, ADI decided the GPR would produce no useful results. Therefore, it was not used. Positional information from the independent odometer system, recording of control line crossings, and DGPS were used to provide the required tolerance of ± 15 cm. Real-time monitoring of performance and target location was provided through audio and graphic profile/contour map displays. Positioned, digital magnetic field measurements at a typical density of 20,000 data points per acre were recorded for post-survey analysis. After each mapping operation, color and isometric images were generated. Computer-aided interpretation provided a listing of the position, depth, and mass of each ferrous object located. The magnetometer is a TM-4 using an array of optically pumped magnetic sensors. In the hand-held mode, one operator carries the magnetometer array while another carries the positioning and data acquisition equipment.

Survey/Operations Summary. Survey was conducted 11 through 19 June 1994, and covered 40 acres.

Support Equipment. None

System Limitations. None reported.

Problems Affecting Survey. No significant problems.

AUSTRALIAN DEFENCE INDUSTRIES (ADI)

Ground **Site: 40 Acre**

System Description

Address:	77 Parramatta Road Silverwater N.S.W. 2141 Australia
Demonstration Dates	6/11/94 to 6/19/94
System Name:	Hand-Held TM4
System Type:	Multimodal
Sensor Name:	GT TM4
Sensor Type:	Magnetometer
Range (claimed):	More than 25 ft
Navigation System:	GT Odometer
Navigation Type:	Rope/Tape/Odometer/GPS
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Image Processing
Area Covered	100%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	45%	48%	52%
Ordnance	43%	46%	52%
Non-Ordnance	47%	50%	51%

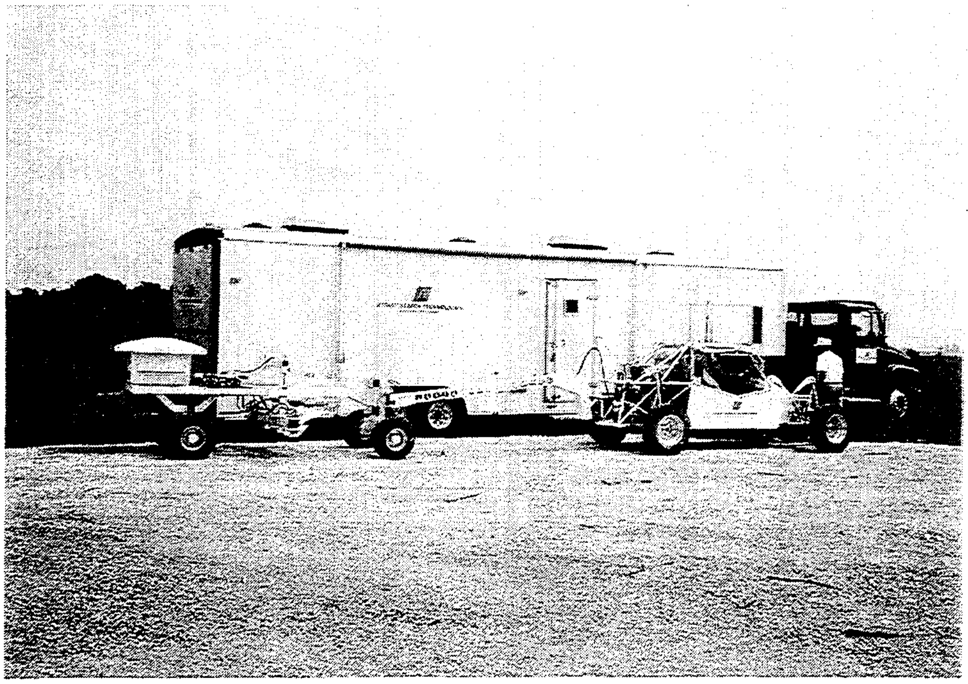
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	92%	92%	82%
False Negative	76%	74%	71%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	44%	48%	54%
Multiple Targets	33%	22%	22%
Small Targets	36%	39%	48%
Medium Targets	54%	59%	58%
Large Targets	52%	54%	54%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	84%	84%	89%
Projectiles	41%	47%	49%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.54	0.67	1.22
Standard Deviation	0.31	0.49	1.24

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.46	0.41	0.39
Standard Deviation	0.53	0.46	0.37



Geo-Centers, Inc.

System Description and Operation. Geo-Centers demonstrated a combination of the STOLS (see Tab 21) and a man-portable magnetometer. For this project, the entire area was surveyed with the vehicular STOLS and missed areas were filled in with the man-portable unit. DGPS was used to provide latitude and longitude coordinates. These can be referenced to a local coordinate system with an accuracy of 0.5 m. Results were presented as magnetic anomaly images, target listings, and computer files showing detected targets, their location, depth, and size classification.

Survey/Operations Summary. Survey was conducted 18 through 26 June 1994 and covered 40 acres.

Support Equipment. One 40-foot trailer/command center with road tractor.

System Limitations. Severe weather, muddy conditions, and heavy foliage.

Problems Affecting Survey. Inclement weather interrupted survey operations.

GEO-CENTERS

Ground | Site: 40 Acre

System Description

Address:	7 Wells Avenue Newton, Massachusetts 02159 (USA)
Demonstration Dates	6/18/94 to 6/26/94
System Name:	Surface Towed Ordnance Locator Sytem (STOLS)
System Type:	Multimodal
Sensor Name:	Geometrics; Scintrex; Foerster
Sensor Type:	Magnetometer
Range (claimed):	**More than 25 ft; btw 5 ft and 9.99 ft; more than 25 ft
Navigation System:	Trimble
Navigation Type:	Differential GPS
Data Proc. Hardware:	UNIX Workstations
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	*100%*

**Range depends on sensor configuration.

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	33%	47%	53%
Ordnance	28%	44%	49%
Non-Ordnance	43%	54%	61%

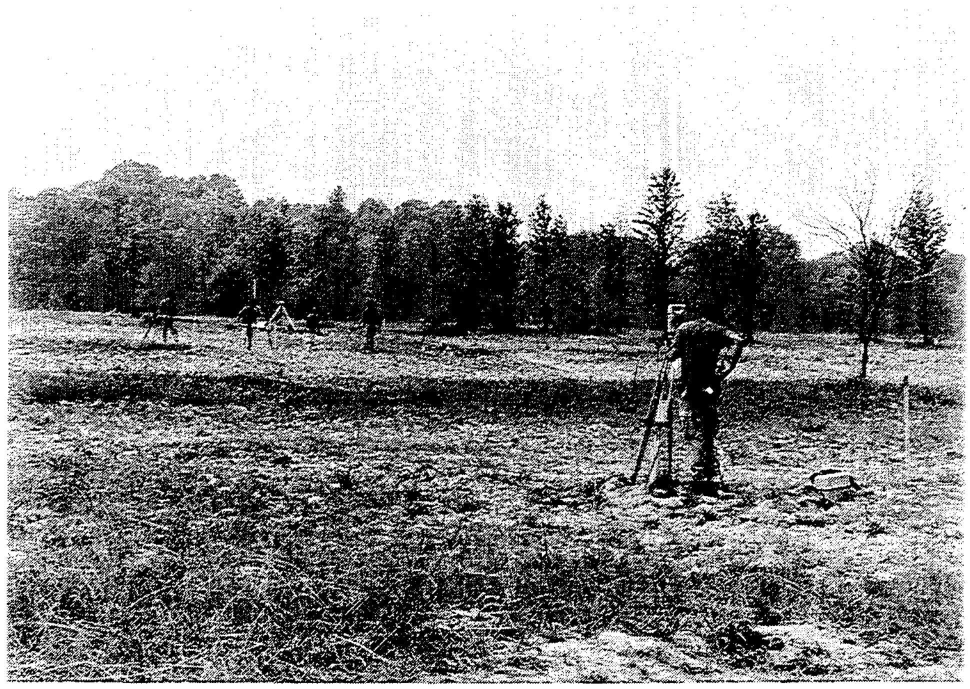
	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	98%
False Negative	85%	76%	73%
Mistyped	0%	0%	0%

	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	27%	43%	49%
Multiple Targets	33%	56%	56%
Small Targets	23%	31%	42%
Medium Targets	35%	61%	64%
Large Targets	48%	64%	62%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	42%	58%	58%
Projectiles	25%	44%	47%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.61	0.93	1.43
Standard Deviation	0.28	0.52	1.15

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.46	0.55	0.52
Standard Deviation	0.62	0.70	0.68



UXB International, Inc.

System Description and Operation. UXB uses a combination of time-proven range clearance sweepline techniques using geophysical instruments and the recording and locating of subsurface contacts with conventional survey equipment. The survey area was divided into 1-acre plots and subdivided into 6-foot-wide search lanes. UXB used the MK26 Ordnance Locator to detect subsurface targets that were marked by a nonmetallic pin flag. Each marked contact was screened using the MK26 to determine size category and approximate depth. When a very strong negative gamma signal was displayed by the MK26, a Schonstedt GA-52B magnetometer was also used. These data were coded on a UXO survey form and flagged for surveyor location. A Total Station surveying instrument was used to establish the data point location. The position and codes were recorded into a data collector and downloaded to the Geographical Information System (GIS). A GIS map and database showing all contacts, their coordinates, and approximate size was produced at the UXB home office and provided as part of the final report.

Survey/Operations Summary. Survey was conducted 18 through 26 June 1994, and covered 28 acres.

Support Equipment. One small trailer.

System Limitations. Metal contamination on ordnance sites (false targets).

Problems Affecting Survey. Severe thunderstorms required leaving the grid temporarily during the survey period. Very high temperatures necessitated periodic work stoppages in accordance with the SHERP.

UXB INTERNATIONAL, Inc.

Ground Based | **Site: 40 Acre**

System Description

Address:	14800 Conference Center Drive Chantilly, Virginia 22021 (USA)
Demonstration Dates	6/18/94 to 6/26/94
System Name:	Magnetometer/total station survey
System Type:	Man-Portable
Sensor Name:	Foerster
Sensor Type:	Magnetometer
Range (claimed):	Btw 15 and 19.99 ft
Navigation System:	Topcon 302
Navigation Type:	Survey Instrument
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	PC Software; QA/QC; Mapping
Area Covered	70%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	37%	43%	45%
Ordnance	29%	36%	38%
Non-Ordnance	55%	58%	61%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	0%	0%	0%
False Negative	*	*	*
Mistyped	100%	100%	100%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	31%	37%	40%
Multiple Targets	0%	0%	0%
Small Targets	24%	27%	31%
Medium Targets	48%	55%	55%
Large Targets	30%	39%	39%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.41	0.57	0.93
Standard Deviation	0.29	0.49	1.17

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.50	0.52	0.49
Standard Deviation	0.54	0.54	0.52

* Ordnance or Non-Ordnance Not Declared

EODT Services, Inc.

System Description and Operation. EODT Services used the Data Acquisition Navigation System (DANS). DANS is a self-contained data collection system that consists of a survey team, navigation system, computer hardware and software system, sensors, and a power supply. EODT Services used two man-portable systems in its demonstration. The systems consisted of the EM-31 Terrain Conductivity Meter and the Schonstedt GA-52B Magnetic Locator. DANS used the GeoDAPS navigation system to record the position and to add the sensor readings. The data was transmitted via RF link to a monitoring station where it was displayed in real time on a computer. Data from the monitoring station was then used to develop contour plots in various coordinate systems as required. The final off-line product included maps of features and anomalies found on the site.

Survey/Operation Summary. Survey was conducted 23 through 31 July 1994, and covered 9.6 acres.

Support Equipment. One 3/4-ton GMC van with a gas-powered electrical generator.

System Limitations. Susceptible to RF interference.

Problems Affecting Survey. None noted.

EODT SERVICES, Inc.

Ground | Site: 40 Acre

System Description

Address:	10500 Hardin Valley Knoxville, Tennessee 37932 (USA)
Demonstration Dates	7/23/94 to 7/31/94
System Name:	DANS/GEODAPS
System Type:	Man-Portable
Sensor Name:	Schonstedt; EM-31
Sensor Type:	Magnetometer; Conductivity Sensor
Range (claimed):	Btw 2 ft and 4.99 ft; btw 10 ft and 14.99 ft
Navigation System:	GEODAPS
Navigation Type:	Differential GPS
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	*24%*
	**Range depends on sensor configuration.

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	3%	7%	9%
Ordnance	3%	7%	10%
Non-Ordnance	6%	6%	6%

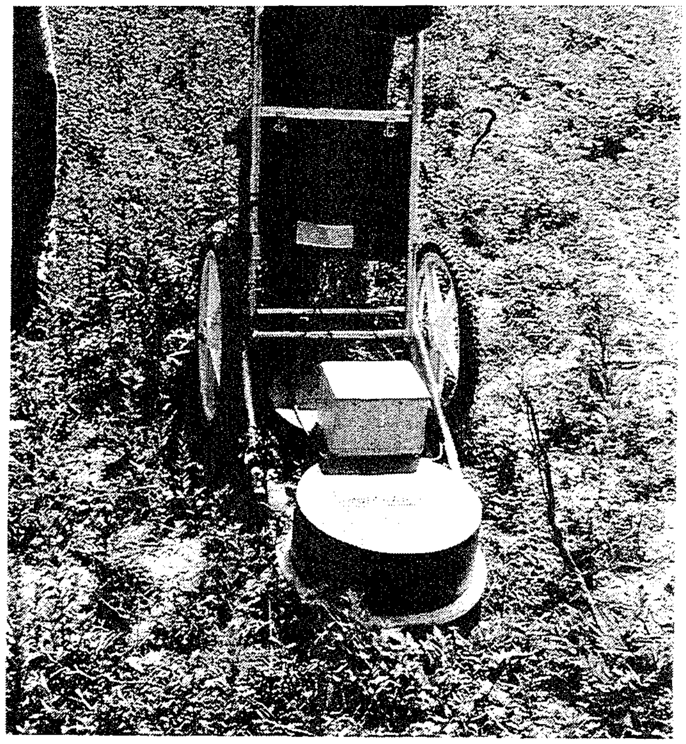
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	95%	87%	82%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	3%	7%	9%
Multiple Targets	0%	0%	50%
Small Targets	4%	6%	8%
Medium Targets	0%	13%	7%
Large Targets	5%	5%	14%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.83	1.27	1.69
Standard Deviation	0.47	0.62	0.84

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-



GeoRadar, Inc.

System Description and Operation. GeoRadar operated a stepped-FM GPR system. The system consists of a two-wheeled, pulled array containing a transmitting and receiving antenna (both low friction), the electronics package, the liquid crystal display, and a battery. The system is self-contained. The unit used was a preproduction model. GeoRadar's GPR system is classified as a stepped-frequency modulation array. The radar transmits signals into the ground and receives reflections from objects that are encountered. Reflections are created whenever the radar signal strikes a material with different electrical properties than the host material, thus enabling it to detect non-conductive objects as well as metal ones. The signals are mixed, and the phase difference is processed through a Fourier Transform to construct the equivalent of a time-domain reflection sequence. Field output was a screen display with capabilities of plotting results on paper. Data was fed and stored using digital signal processing chips and was then downloaded to a computer.

Survey/Operations Summary. Survey was conducted 6 through 14 August 1994 and covered 1.6 acres.

Support Equipment. None

System Limitations. Very low survey speed.

Problems Affecting Survey. Inclement weather and equipment failures caused over 6 hours of downtime.

GEORADAR, Inc.

Ground | Site: 40 Acre

System Description

Address:	19623 Via Escuela Drive Saratoga, California 95070 (USA)
Demonstration Dates	8/6/94 to 8/14/94
System Name:	GeoRadar 1000A
System Type:	Man-Portable
Sensor Name:	GeoRadar
Sensor Type:	Ground Penetrating Radar
Range (claimed):	Btw 5 ft and 9.99 ft
Navigation System:	None
Navigation Type:	None
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	*4%*

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	0%	14%	14%
Ordnance	0%	20%	20%
Non-Ordnance	0%	0%	0%

	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	*	*	*
False Negative	100%	96%	95%
Mistyped	*	0%	0%

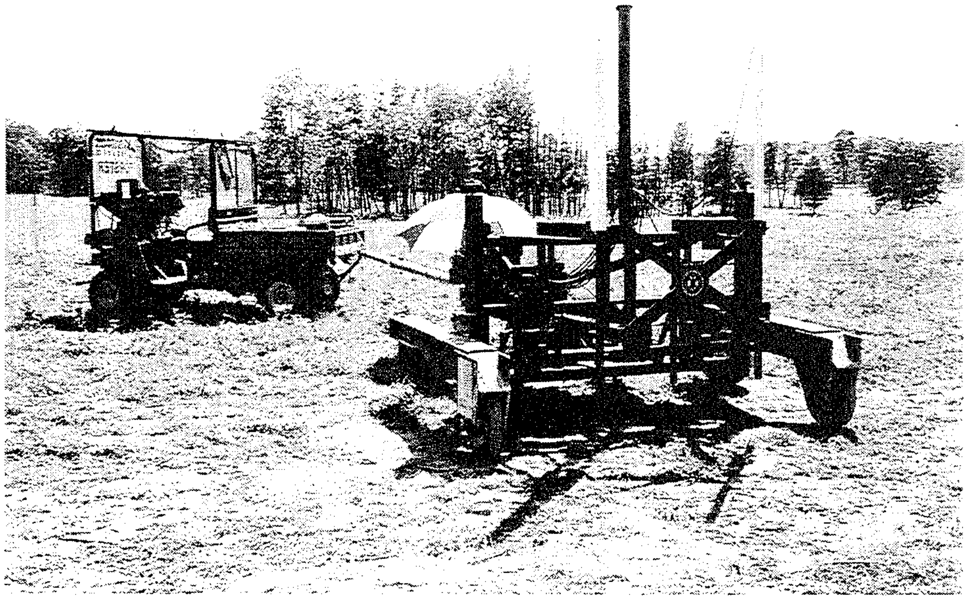
	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	0%	20%	20%
Multiple Targets	-	-	-
Small Targets	0%	0%	0%
Medium Targets	0%	50%	50%
Large Targets	0%	0%	0%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	-	-	-

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	1.90	1.90
Standard Deviation	-	-	-

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	0.28	0.28
Standard Deviation	-	-	-

* All Targets Declared Indiscriminately As Ordnance



Foerster Instruments, Inc.

System Description and Operation. The Foerster system was called the Vehicle Mounted Differential Global Positioning System Controlled Combined Shallow/Deep Search Survey System. The system was equipped with an array of FEREX and MINEX Sensors mounted perpendicular to the driving direction. The array is mounted on a towed platform constructed predominantly of wood, with brass and fiberglass composite components. The sensors provide a detection sweep width of 2-m. The platform is towed by a Kawasaki four-wheel drive vehicle that contained a generator and the navigation equipment. Five MINEX Sensors, able to detect all metals and used for land mine detection, were mounted on the front of the array. Four FEREX gradient magnetometer sensors, usually hand-carried, were mounted in the center area of the array. Two modified (elongated) FEREX sensors, called deep search sensors, were mounted at the rear of the array and were designed to extend the detection range to a greater depth. In addition, a data logger attached to a hand-carried FEREX sensor, was used to check the areas near trees. The landscape software presented a map of the entire search area showing specific markings such as corner grid points. It was also able to provide a grid system adapted to the intended tracks of the vehicle such as the 100 by 100-foot grid at JPG.

Survey/Operations Summary. Survey was conducted 13 through 21 August 1994, and covered 20.8 acres.

Support Equipment. One large Ryder rental van.

System Limitations. Limitations of muddy or rough terrain.

Problems Affecting Survey. Some breakage occurred to the wooden components of the towed platform, but they were quickly repaired.

FOERSTER INSTRUMENTS, Inc.

Ground | Site: 40 Acre

System Description

Address:	140 Industry Drive Pittsburgh, Pennsylvania 15275-1028 (USA)
Demonstration Dates	8/13/94 to 8/21/94
System Name:	VEMO-SDSS
System Type:	Multimodal
Sensor Name:	MINEX 2FD; FEREX DS; FEREX MK26
Sensor Type:	Magnetometer
Range (claimed):	**Btw 1 foot and 1.99 ft; btw 20 ft and 24.99 ft; btw 15 and 19.99 ft
Navigation System:	Custom GPS
Navigation Type:	Differential GPS
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Multi-Sensor Signal Processing
Area Covered	*52%*
	**Range depends on sensor configuration.

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	28%	41%	56%
Ordnance	27%	37%	52%
Non-Ordnance	32%	50%	64%

	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	93%	89%	85%
Mistyped	0%	0%	0%

	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	28%	38%	52%
Multiple Targets	0%	25%	50%
Small Targets	15%	21%	45%
Medium Targets	41%	66%	69%
Large Targets	41%	57%	61%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	7%	13%	13%
Mortars	6%	6%	14%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.63	0.91	1.73
Standard Deviation	0.31	0.52	1.32

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.51	0.49	0.46
Standard Deviation	0.63	0.63	0.57

Metratek (Ground)

System Description and Operation. Metratek demonstrated two technologies, a GPR system mounted on a sled towed by a four-wheel drive vehicle and a GEONICS EM61 Active Electronic Sensor (AES) mounted on a hand-drawn cart. The self-contained, man-portable AES was provided by the Johns Hopkins University Applied Physics Laboratory (JHU/APL). The cart is made of fiberglass and moves on two large diameter wheels. The sensor coils are integral with the frame and consist of two 1 m by 1 m horizontal frames that are about 40 cm apart. The bottom frame holds both the transmitter and the receiver coils. The top frame holds a secondary receiver (focusing) coil used to determine target depth. A backpack houses the processing electronics, battery pack, main circuit breaker, and monitoring components. The AES system operates over the frequency range of 100 Hz to 20 kHz to provide deep ground penetration with lower resolution. Multiple simultaneous frequencies and shaped pulse waveforms are used. The shaped pulses are optimized for returns from different depths. Analysis of the data is designed to display and detect multiple-frequency and pulse signatures while rejecting background noise and clutter.

Survey/Operations Summary. Survey was conducted 13 through 21 August 1994, and covered 4.4 acres.

Support Equipment. None.

System Limitations. The towed GPR may experience problems in mud and heavy vegetation.

Problems Affecting Survey. The GPR did not function until the last hour of the demonstration. Consequently, the JHU/APL man-portable system performed the majority of the survey conducted.

METRATEK (Ground)

Ground | Site: 40 Acre

System Description

Address:	12330 Pinecrest Road Reston, Virginia 22091 (USA)
Demonstration Dates	8/13/94 to 8/21/94
System Name:	Model 200 Prototype GPR
System Type:	Multimodal/Multisensor
Sensor Name:	METRATEK; Geonics EM-61
Sensor Type:	Ground Penetrating Radar; Conductivity Sensor
Range (claimed):	**Btw 15 and 19.99 ft; btw 10 ft and 14.99 ft
Navigation System:	Trimble; tape
Navigation Type:	Differential GPS; Rope/Tape/Odometer
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	*11%*
	**Range depends on sensor configuration.

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	17%	25%	33%
Ordnance	19%	31%	44%
Non-Ordnance	13%	13%	13%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	94%	90%	85%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	19%	31%	44%
Multiple Targets	-	-	-
Small Targets	0%	13%	25%
Medium Targets	29%	43%	43%
Large Targets	29%	29%	43%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	25%
Projectiles	0%	0%	14%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	-	-	-

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.56	0.89	1.50
Standard Deviation	0.31	0.56	1.11

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

Dynamic Systems, Inc.

System Description and Operation. The system brought to JPG included MK26 gradient magnetometers for target detection, Billingsley Magnetics triaxial fluxgate magnetometer (TFM) with analog and digital outputs, a Fluke Hydra Data Bucket for data acquisition, a notebook computer used primarily for data analysis but as a backup for data acquisition, and Total Station Survey equipment. Search lanes were laid out and swept using an MK26 gradient magnetometer. All contacts were flagged and positions determined using the Total Station Survey equipment. Three string paths were laid in a north-south direction across contacts; one was centered over the flag, and the other two were placed east and west of the flag by approximately 2 feet. The paths were about 26 feet long and were marked at 1-foot intervals. The paths were used to guide the TFM while data was collected. The starting locations for each path were also marked and surveyed. Raw data was downloaded from the Fluke data bucket to a spreadsheet file. The data was reviewed and exported to a tab-delimited file for processing. The processing program was written in Labview for Windows, a graphical programming language similar to Visual Basic. As-reported program parameters were adjusted for a "best fit" of the data to theory. In this manner, target location and target magnetic strength were determined.

Survey/Operation Summary. Survey was conducted 20 through 28 August 1994 and covered 4.8 acres.

Support Equipment. None

System Limitations. Present system is tedious to operate and is not optimized for field use.

Problems Affecting Survey. Dynamic Systems was authorized to deviate from the original proposal; identification technology was demonstrated, not detection capability.

DYNAMIC SYSTEMS, Inc.

Ground | Site: 40 Acre

System Description

Address:	635 Slaters Lane Alexandria, Virginia 22314 (USA)
Demonstration Dates	8/20/94 to 8/28/94
System Name:	Triaxial Fluxgate Magnetometer
System Type:	Man-Portable
Sensor Name:	Billingsley
Sensor Type:	Magnetometer
Range (claimed):	Btw 15 and 19.99 ft
Navigation System:	Topcon 302
Navigation Type:	Survey Instrument
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	"Best Fit Analysis"
Area Covered	*12%*

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	35%	35%	35%
Ordnance	29%	29%	29%
Non-Ordnance	57%	57%	57%

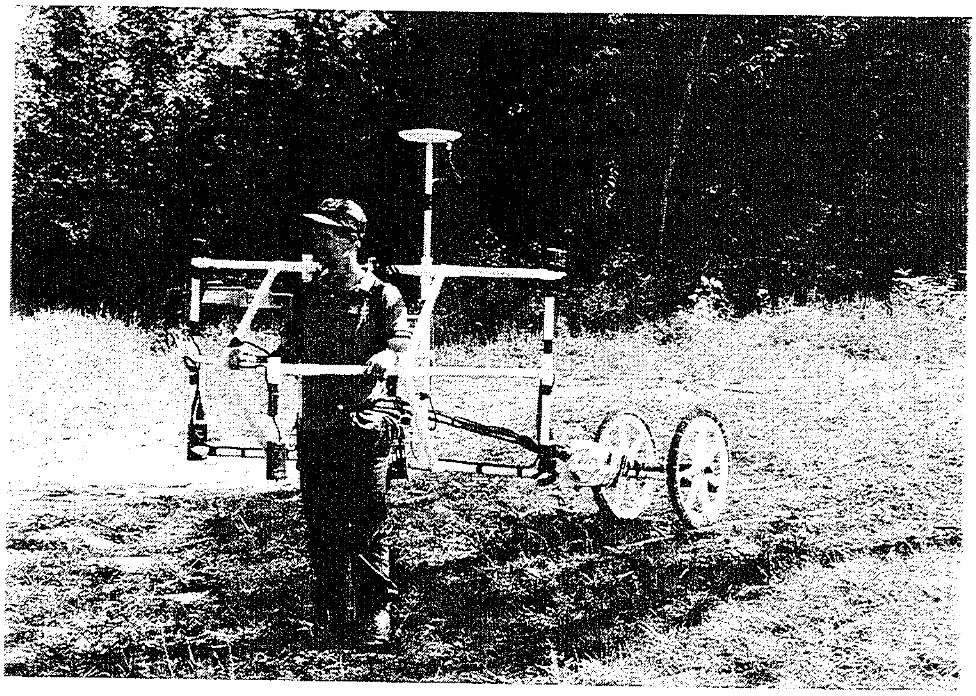
	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	65%	65%	65%
Mistyped	0%	0%	0%

	Type Detection Ratios		
Critical Radius	1 m	2 m	5 m
Single Targets	30%	30%	30%
Multiple Targets	0%	0%	0%
Small Targets	25%	25%	25%
Medium Targets	50%	50%	50%
Large Targets	36%	36%	36%

	Classification Ratios		
Critical Radius	1 m	2 m	5 m
Bombs	50%	50%	50%
Projectiles	30%	30%	30%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.44	0.44	0.44
Standard Deviation	0.27	0.27	0.27

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.31	0.31	0.31
Standard Deviation	0.18	0.18	0.18



Geometrics, Inc.

System Description and Operation. Geometrics used a Magnetic Detection and Identification System (MagDIS). An array of five cesium vapor magnetometers were mounted on a man-portable PVC structure. MagDIS was configured with two vertical gradiometer arrays (2-foot spacing). Each was separated horizontally by 5 feet in the cross-track direction. A fifth cesium sensor was positioned to provide an along-track horizontal gradient. This, in effect, provided a three-axis gradiometer. At one point during the demonstration, the arrays were tilted to a 45 degree angle to overcome "dead zones" on the survey site. The sensor electronics for each sensor were mounted on an arm that extended 11 feet back from the sensors. The configuration of the magnetometers allowed a distance between survey traverses of 10 feet. Data control, acquisition, and field display units were mounted on a six-wheel all-terrain vehicle (ATV). The ATV followed behind the man-portable unit and was connected to the electronic sensors by a 40-foot umbilical cable. Six 12-volt batteries were used to power the system. MagDIS used an Ashtech DGPS and a heading sensor (Accelerometer) to provide submeter positioning information. The Magnetometer and Accelerometer Data were collected on an 486 DC-powered logging computer and were processed using Geometric's custom software on a Unix-based Sun Workstation. The raw GPS data were collected on a 46 Toshiba laptop and were processed using an Ashtech PNAV (Precise Navigation) System.

Survey/Operation Summary. Survey was conducted 17 through 25 September 1994, and covered 33.2 acres.

Support Equipment. None

System Limitations. Limitations of muddy or rough terrain.

Problems Affecting Survey. Equipment failures caused about 6.5 hours of downtime.

GEOMETRICS, Inc.

Ground — Site: 40 Acre

System Description

Address:	395 Java Drive Sunnyvale, California 94089 (USA)
Demonstration Dates	9/17/94 to 9/25/94
System Name:	MagDIS
System Type:	Man-Portable
Sensor Name:	Geometrics
Sensor Type:	Magnetometer
Range (claimed):	More than 25 ft
Navigation System:	Ashtech; Fiducials
Navigation Type:	Differential GPS; Rope/Tape/Odometer
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	83%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	9%	23%	29%
Ordnance	10%	24%	31%
Non-Ordnance	7%	21%	26%

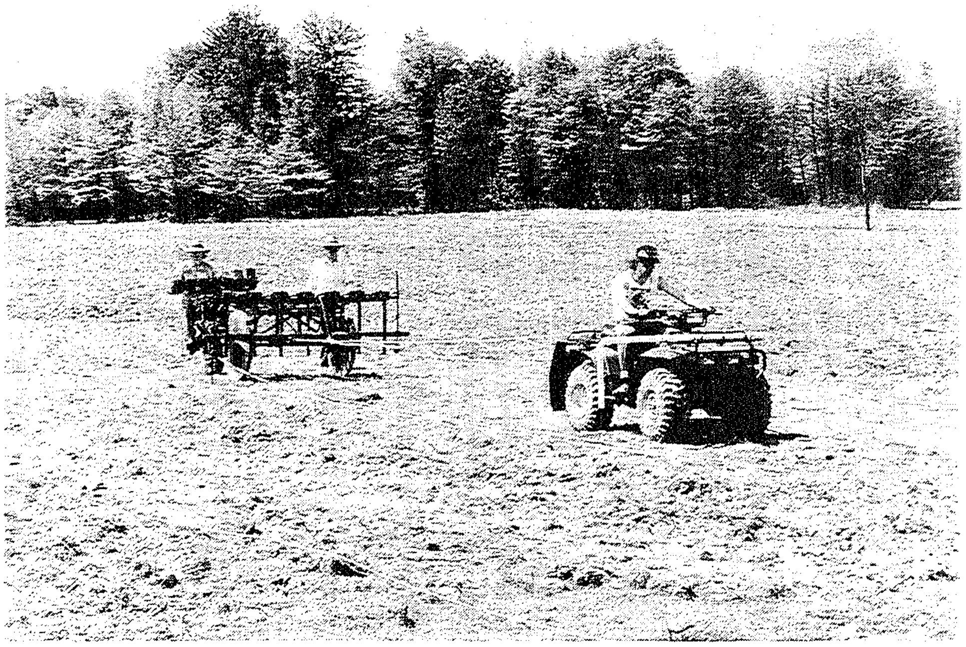
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	89%	74%	65%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	10%	25%	32%
Multiple Targets	13%	0%	13%
Small Targets	6%	11%	16%
Medium Targets	9%	32%	40%
Large Targets	12%	34%	42%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	11%	26%	32%
Projectiles	7%	29%	34%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.73	1.32	1.78
Standard Deviation	0.24	0.54	0.95

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.75	0.72	0.66
Standard Deviation	0.34	0.42	0.47



Security Search Products (Vallon)

System Description and Operation. The system consisted of a towed array of five Vallon magnetometer search probes mounted on a trailer towed by an ATV. Each search probe was supported by an MC1 Micro Computer and EVA (PC-DOS) software program to provide "High Definition Magnetics" for the detection of buried UXO. The MC1 is a menu-driven, data acquisition/data evaluation unit carried on-board the Vallon EL1302A1 Ferrous Locator. The operator is provided with a real-time illustration of the survey data to provide on-the-spot analysis, or data may be stored and downloaded to the EVA software for overall field analysis. The processed data provided an X-Y-Z coordinate map of the surveyed site with precise (within 5 cm) target location and identification. Prior to the survey, sensor-position-system (SEPOS) guidelines were manually laid out. The lines were 100 m in length and were marked each meter with a marker detector. Each marker was sub-recorded by the MC1. By using the SEPOS lines the MC1 automatically calculated any deviations in speed or in the course of the ATV that could alter the accuracy of the survey.

Survey/Operations Summary. Survey was conducted 21 through 29 May 1994, and covered 11.6 acres.

Support Equipment. One Jeep Wagoneer.

System Limitations. Manual lane marking is time consuming.

Problems Affecting Survey. Two magnetometers had to be removed from the modular system to conform to the proposed configuration.

SECURITY SEARCH PRODUCTS (VALLON)

Ground | Site: 40 Acre

System Description

Address:	Im Grund 3 Eningen, Germany 72800
Demonstration Dates	5/21/94 to 5/29/94
System Name:	MC1 with SEPOS and EVA on MSV5
System Type:	Towed/ManPod
Sensor Name:	Vallon
Sensor Type:	Magnetometer
Range (claimed):	Btw 20 ft and 24.99 ft
Navigation System:	SEPOS
Navigation Type:	Rope/Tape/Odometer
Data Proc. Hardware:	MC1 Micro Computer
Data Proc. Method:	EVA (PC DOS) Software
Area Covered	29%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	54%	65%	79%
Ordnance	52%	59%	76%
Non-Ordnance	57%	74%	83%

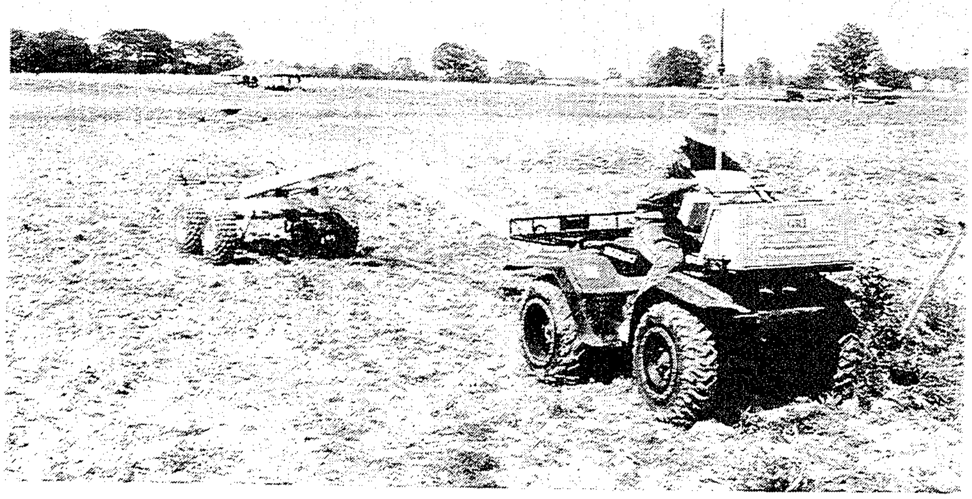
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	98%	98%	97%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	48%	56%	74%
Multiple Targets	100%	100%	100%
Small Targets	50%	58%	69%
Medium Targets	40%	80%	90%
Large Targets	67%	67%	87%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	50%	50%	67%
Projectiles	44%	67%	78%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.44	0.68	1.25
Standard Deviation	0.27	0.52	1.28

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.44	0.38	0.45
Standard Deviation	0.68	0.63	0.70



Australian Defence Industries (ADI)

System Description and Operations. ADI proposed a combination of hand-held and vehicle-mounted magnetic and GPR technologies during the demonstration. The magnetic system used a total field magnetometer and computer-aided interpretation of the magnetic data to provide a list of position, depth, and approximate mass of targets. The GPR system was to be used to confirm those parameters. However, the GPR was not used during the demonstration at JPG. Positional information from the independent odometer system, recording of control line crossings, and DGPS were used to provide the required tolerance of ± 15 cm. Real-time monitoring of performance and target location was provided through audio and graphic profile/contour map displays. Positioned, digital magnetic field measurements at a typical density of 20,000 data points per acre were recorded for post-survey analysis. After each mapping operation, color and isometric images were generated. Computer-aided interpretation provided a listing of the position, depth, and mass of each ferrous object located. The magnetometer is a TM-4 using an array of optically pumped magnetic sensors. In the vehicle-mounted configuration, dual magnetic sensors are mounted on a small, non-magnetic trailer and towed by a commercial quad-cycle. Data acquisition and the DGPS navigation equipment are located on the quad-cycle.

Survey/Operations Summary. Survey was conducted 11 through 19 June 1994, and covered 40 acres.

Support Equipment. One forklift.

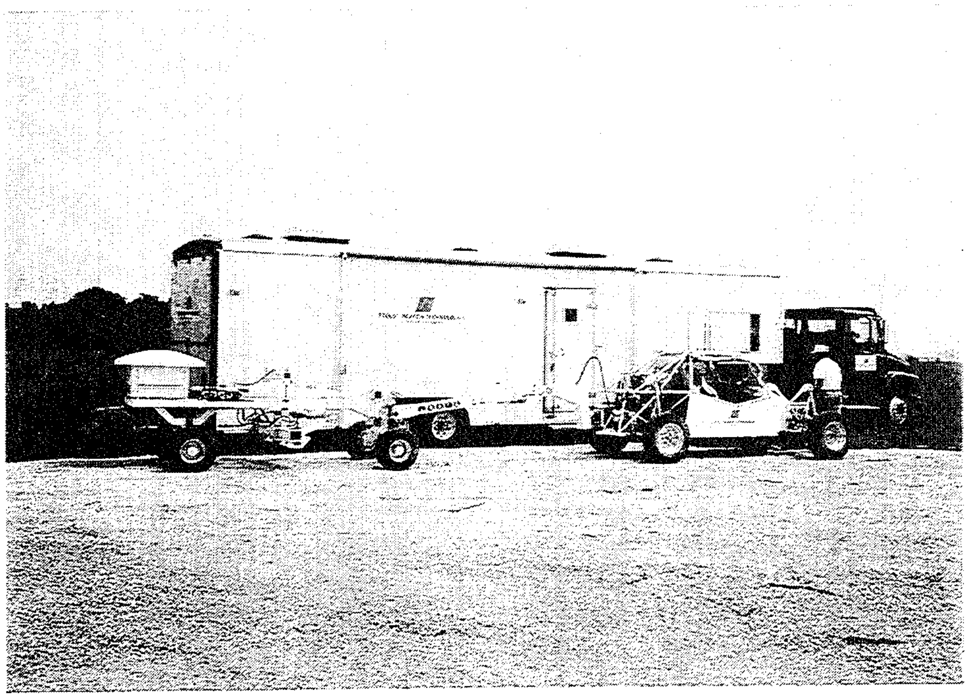
System Limitations. None reported.

Problems Affecting Survey. No significant problems.

AUSTRALIAN DEFENCE INDUSTRIES

Note

Demonstrator results for multimodal systems were reported and processed as a single Demonstrator Target Set. Refer to Tab 10 for the results for this demonstrator.



Geo-Centers, Inc.

System Description and Operation. Geo-Centers demonstrated a combination of the STOLS and a man-portable magnetometer. The STOLS is a ground mobile system consisting of a low magnetic signature, all-terrain tow vehicle; a low magnetic signature tow platform; an array of seven cesium vapor total field magnetometers; a precision DGPS; and on-board computers for data collection, compression, and storage. For this project, the entire area was surveyed with the vehicular STOLS, with missed areas filled in with a portable unit. The DGPS provides latitude and longitude coordinates. These can be referenced to a local coordinate system with an accuracy of 0.5 m. Results were presented as magnetic anomaly images, target listings, and computer files showing detected targets, their location, depth, and size classification.

Survey/Operations Summary. Survey was conducted 18 through 26 June 1994, and covered 40 acres.

Support Equipment. One 40-foot trailer/command center with tractor.

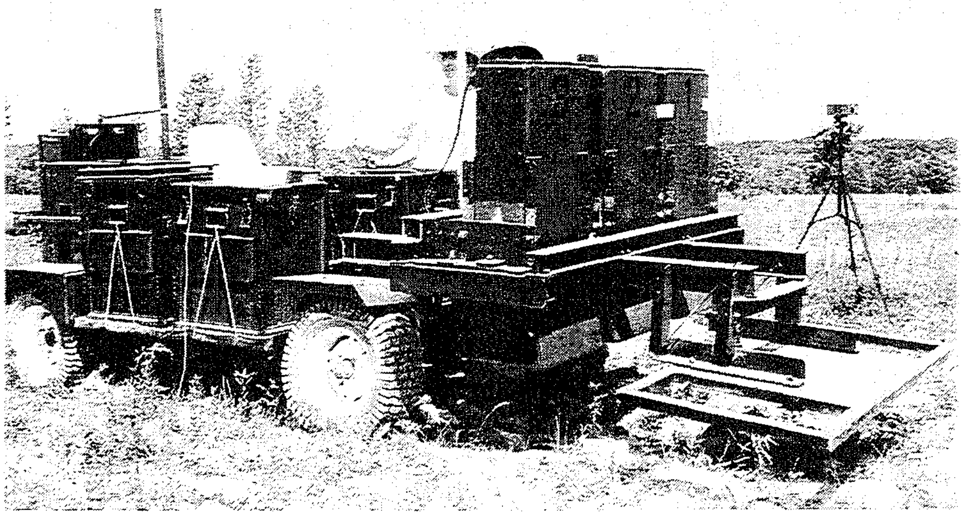
System Limitations. Severe weather, muddy conditions, and heavy foliage.

Problems Affecting Survey. The towed trailer experienced a broken weld and needed to be repaired.

GEO-CENTERS, INC.

Note

Demonstrator results for multimodal systems were reported and processed as a single Demonstrator Target Set. Refer to Tab 11 for the results for this demonstrator.



Chemrad (EG&G)

System Description and Operation. The MIRADOR remote controlled, self-propelled sensor platform weighs 1,500 lbs. and measures approximately 6 feet wide by 10 feet long. The system combines outputs from three GPRs and three Metal Detectors (MD) to produce a composite result. This data fusion process can accommodate sensor data containing gaps, noise, dropouts, and other flaws, and still provide enhanced target detection and location. The three very low power GPRs are designed to perform non-intrusive surveys of soils and related materials near the surface (within 1 m). The horns, mounted at a height of 0.3 m, are pointed straight down to optimize pulse transmission into the ground. The RF emissions from the radars range from about 100 MHz to 5 GHz, with a pulse width of 1 nanosecond. The peak transmitting power is 2 watts and the average power is less than 100 milliwatts. The USRADS was used for tracking with on-screen location and bearing information. Power to the USRADS was supplied by a gas-powered generator. The USRADS System broadcasts an ultrasonic signal (19.4 KHz) once per second from the survey platform. As the signal propagates over the survey area, it is detected by transponders positioned at known locations. The arrival times at each transponder are used to calculate the distances from the emitter and to calculate the emitter's location to within ± 6 inches. Up to six channels of survey data may be transmitted from the surveyor to the field computer via RF transmissions once per second.

Survey/Operations Summary. Survey was conducted 9 through 17 July 1994, and covered 14 acres.

Support Equipment. None

System Limitations. System requires a smooth flat surface for optimum operation. The USRADS navigation system is susceptible to acoustic interference.

Problems Affecting Survey. No significant problems.

CHEMRAD (EG&G)

Ground | Site: 40 Acre

System Description

Address:	1055 Commerce Park Oak Ridge, Tennessee 37830 USA
Demonstration Dates	7/9/94 to 7/17/94
System Name:	MIRADOR
System Type:	Self-Powered
Sensor Name:	Gulf Applied
Sensor Type:	Ground Penetrating Radar/Magnetometer
Range (claimed):	Btw 5 ft and 9.99 ft
Navigation System:	USRADS
Navigation Type:	Acoustic Positioning System
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	*35%*

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	2%	13%	23%
Ordnance	2%	9%	18%
Non-Ordnance	4%	21%	32%

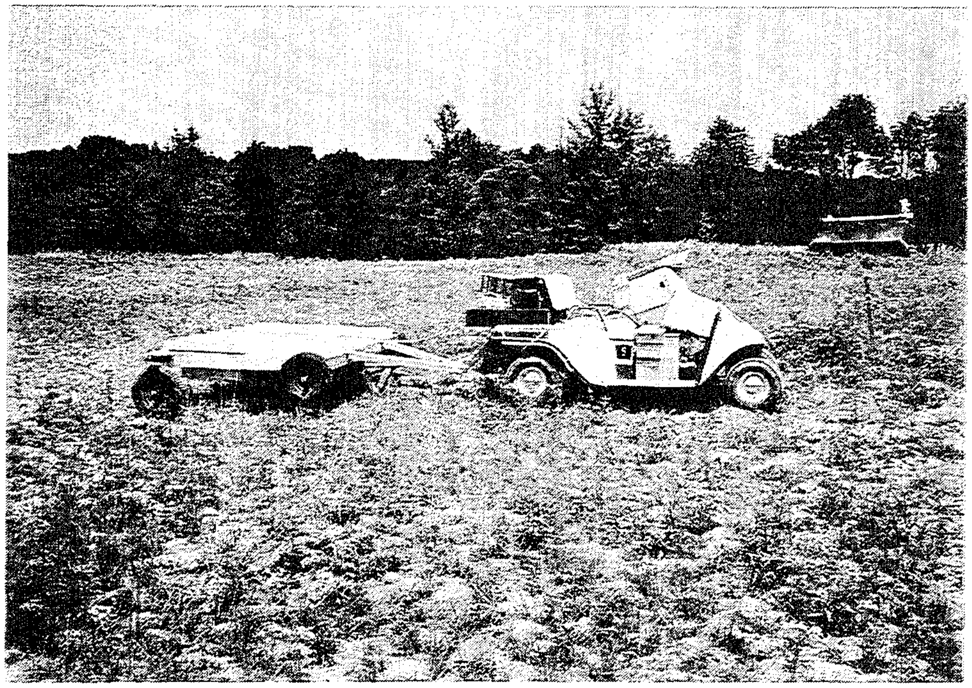
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	99%	97%	94%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	2%	10%	15%
Multiple Targets	0%	0%	67%
Small Targets	0%	4%	19%
Medium Targets	0%	10%	19%
Large Targets	6%	24%	30%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	9%	9%
Projectiles	0%	9%	18%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	1.06	1.64	2.78
Standard Deviation	0.58	0.49	1.27

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.32	0.92	0.51
Standard Deviation	0.23	1.15	0.54



GDE Systems, Inc.

System Description and Operations. The demonstrated prototype used a tow vehicle that carried a transmitter, receiver, computer, display terminal, and a gas-powered 110-volt generator. The cart pulled a trailer with an array of five antennas connected by an electronic switch to the source and receiver. Antenna operation was monostatic; that is one antenna radiates and receives at a given time. The system sampled reflectance magnitude as the vehicles moved, and stored data in rows, with five values per row, to synthesize data over a swath. The system operated at 196 MHz and has a 6-foot-wide swath. Position data in the travel direction were generated by an encoder motor connected to a trailer wheel. The system moved in a straight line to synthesize swaths of data, which were recorded on disk. Starting positions were recorded in a log. During the travel, position and reflectance data were stored on disks and displayed. Plotting and printing took place post-survey. System operation depends on frequency (which influences detection depth), ordnance (mainly size and composition), and soil moisture (wetter soil and deeper objects require a system that uses longer wavelengths). The system generates plan views (horizontal sections), which help identification by defining ordnance shape. Plan view images can be more easily interpreted than the vertical section display of conventional GPR.

Survey/Operations Summary. Survey was conducted 9 through 17 July 1994, and covered 6.4 acres.

Support Equipment. None

System Limitations. Detection capability dependent on soil conditions.

Problems Affecting Survey. System was not weatherproof. Tow vehicle failures caused about 4 hours of downtime. When the original golf cart tow vehicle failed, a Gator ATV was rented for the demonstration.

GDE SYSTEMS, Inc.

Ground | Site: 40 Acre

System Description

Address:	PO Box 85227 San Diego, California 92186 (USA)
Demonstration Dates	7/9/94 to 7/17/94
System Name:	Imaging GPR Sensor
System Type:	Towed
Sensor Name:	GDE SYSTEMS
Sensor Type:	GPR
Range (claimed):	Btw 10 ft and 14.99 ft
Navigation System:	MANUAL/ENCODER
Navigation Type:	Rope/Tape/Odometer
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	16%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	9%	23%	36%
Ordnance	12%	32%	48%
Non-Ordnance	5%	11%	21%

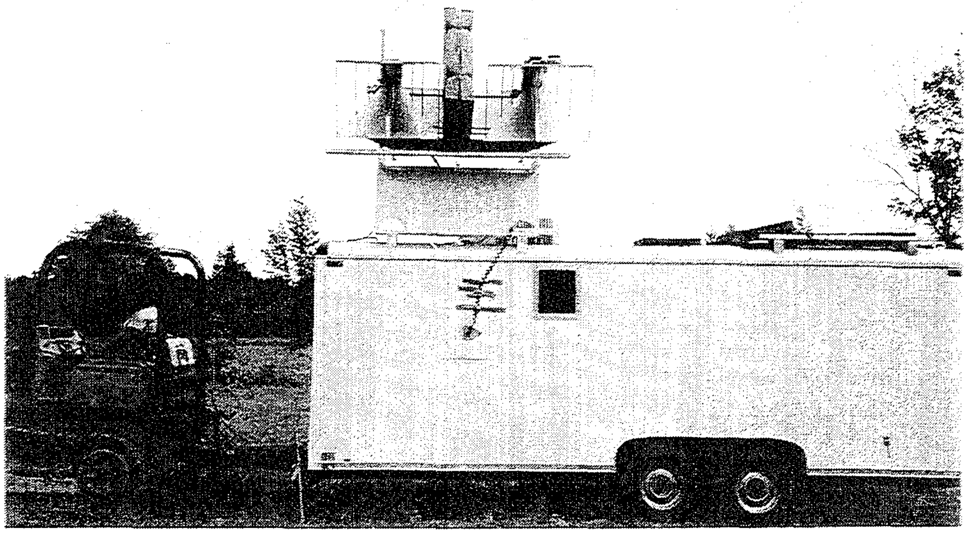
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	100%	99%	98%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	10%	33%	52%
Multiple Targets	25%	25%	25%
Small Targets	6%	25%	25%
Medium Targets	0%	20%	30%
Large Targets	20%	27%	53%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	17%	33%	50%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.67	1.37	2.04
Standard Deviation	0.28	0.57	1.02

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	0.23
Standard Deviation	-	-	-



SRI International (Ground)

System Description and Operation. The SRI Ground system is a self-contained, GPR, towed system. The 20-feet-long trailer holds a side-looking, GPR system. It has a transmit horn and a receive horn, both mounted on the roof of the trailer. Transmitted pulses are triggered every 0.25 inches (or multiple thereof) by an encoder mounted on the trailer wheel. Time and position information is recorded using a GPS system. Differential GPS is obtained by post-processing with data from a stationary GPS system running simultaneously. Data processing involves clutter reduction of the RF data followed by image generation using synthetic aperture radar techniques. Buried targets are identified by comparing the radar images with known surface features at the site of interest.

Survey/Operation Summary. Survey was conducted 23 through 31 July 1994, and covered 11.6 acres.

Support Equipment. Two gas-powered generators and a front-end loader to pull the trailer.

System Limitations. Limited operation in wet or extremely rough terrain.

Problems Affecting Survey. Rough terrain and trees reduced the acreage surveyed. Equipment failures caused almost 9.5 hours of downtime.

SRI INTERNATIONAL (Ground)

Ground | Site: 40 Acre

System Description

Address:	333 Ravenswood Avenue Menlo Park, California 94025 (USA)
Demonstration Dates	7/23/94 to 7/31/94
System Name:	Trailer GPR
System Type:	Towed
Sensor Name:	Custom
Sensor Type:	Ground Penetrating Radar
Range (claimed):	Btw 2 ft and 4.99 ft
Navigation System:	Ashtech
Navigation Type:	Differential GPS
Data Proc. Hardware:	Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	29%

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	0%	1%	2%
Ordnance	0%	0%	2%
Non-Ordnance	0%	4%	4%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	*	0%	0%
False Negative	*	*	*
Mistyped	*	*	100%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	0%	0%	0%
Multiple Targets	0%	0%	0%
Small Targets	0%	0%	0%
Medium Targets	0%	0%	0%
Large Targets	0%	0%	4%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	1.96	3.01
Standard Deviation	-	-	1.49

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

* Ordnance or Non-Ordnance Not Declared

ENSCO, Inc.

System Description and Operation. ENSCO operates a self-contained GPR towed system. The GPR system consists of the following five major subsystems: the GPR controller, the display and data recorder, the transmitting antenna, the receiving antenna, and the power system. The transmitter and receiver antennas were mounted on a sled and towed across the grid by a modified golf cart. ENSCO's GPR system is classified as a short pulse (SPR) or in pulse radar. The SPR generates a source signal by applying a very short pulse of high voltage to the transmitting antenna system. This pulse causes a relatively broadband burst of electromagnetic energy to be radiated from the antenna. The signals from the transmitting antenna are coupled into the ground by matching the impedance of the antenna to that of the surrounding soil. The receiving antenna acquires the energy that is dispersed or reflected from anomalies in the ground beneath and between the two antennas. The SPR return signals are acquired from the receiving antenna in the time domain, reportedly allowing direct measurements of the depth and extent of the anomaly. The measurements are made based on time of arrival and velocity of propagation. The data is processed with a Unix Sun workstation, using software developed by ENSCO.

Survey/Operation Summary. Survey was conducted 30 July through 7 August 1994 and covered 9.2 acres.

Support Equipment. One 6x6 ATV.

Systems Limitations. Wet soil decreases system effectiveness. Tow vehicle had very little ground clearance.

Problems Affecting Survey. No significant problems.

ENSCO, Inc.

Ground — Site: 40 Acre

System Description

Address:	5400 Port Royal Road Springfield, Virginia 22151-2312 (USA)
Demonstration Dates	7/30/94 to 8/7/94
System Name:	Subsurface Ordnance Loc. Equip.
System Type:	Towed
Sensor Name:	GSSI SIR10
Sensor Type:	Ground Penetrating Radar
Range (claimed):	**Btw 5 ft and 9.99 ft; btw 15 and 19.99 ft; btw 10 ft and 14.99 ft
Navigation System:	Laser Track; Survey Wheel
Navigation Type:	Survey Instrument
Data Proc. Hardware:	UNIX Workstations; Personal Computer
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	*23%*

**Range depends on sensor configuration.

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	0%	3%	38%
Ordnance	0%	4%	39%
Non-Ordnance	0%	0%	36%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	*	*	100%
False Negative	100%	100%	95%
Mistyped	*	0%	0%

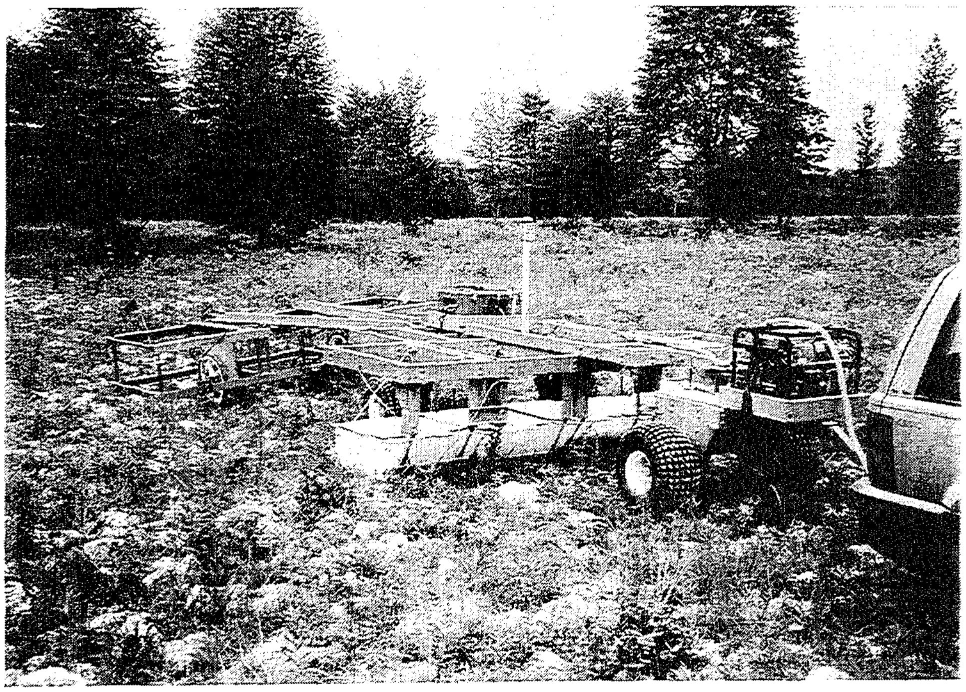
Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	0%	4%	37%
Multiple Targets	0%	0%	100%
Small Targets	0%	0%	44%
Medium Targets	0%	11%	38%
Large Targets	0%	0%	57%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	40%
Projectiles	0%	0%	38%
Mortars	0%	0%	36%
Mines	-	-	-
Clusters	0%	0%	100%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	1.99	3.24
Standard Deviation	-	-	0.96

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	0.16	0.51
Standard Deviation	-	-	0.49

* All Targets Declared Indiscriminately As Ordnance



Coleman Research Corporation (CRC)

System Description and Operation. CRC operated an Earth Penetrating Radar Imaging System (EPRIS). EPRIS combines a frequency-stepped radar with synthetic aperture imaging algorithms. The system consists of an array of five antennas that were mounted on a fiberglass frame pulled behind a Jeep Grand Cherokee. Also attached to the system was an array of three electro magnetic EM-61 units. CRC uses NAVSTAR XRMS GPS with real-time corrections uplinked via UHF modem. The unit was a prototype system. CRC's system is an adaptation of the ongoing EPRIS program to design a prototype system to detect and locate metallic and non-metallic objects. The system uses synthetic aperture algorithms to generate two-and-three-dimensional images. The EPRIS data processing equipment consists of a verification processor, an image processor, and a silicon graphics workstation.

Survey/Operations Summary. Survey was performed 6 through 14 August 1994, and covered 35.2 acres.

Support Equipment. One large rental truck.

System Limitations. System may encounter problems with rough terrain or heavy vegetation.

Problems Affecting Survey. Inclement weather and equipment failures caused almost 9 hours of downtime.

COLEMAN RESEARCH CORPORATION

Ground | Site: 40 Acre

System Description

Address:	5950 Lakehurst Drive Orlando, Florida 32819-8343 (USA)
Demonstration Dates	8/6/94 to 8/14/94
System Name:	EPRIS
System Type:	Multisensor
Sensor Name:	TDEM EM61
Sensor Type:	Induction Coil
Range (claimed):	Btw 10 ft and 14.99 ft
Navigation System:	DRC Encoder
Navigation Type:	Wheel Mounted Linear Optical Encoder
Data Proc. Hardware:	UNIX Workstations
Data Proc. Method:	Image Processing and Pattern Recognition
Area Covered	*88%*

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	18%	33%	50%
Ordnance	20%	36%	49%
Non-Ordnance	14%	27%	51%

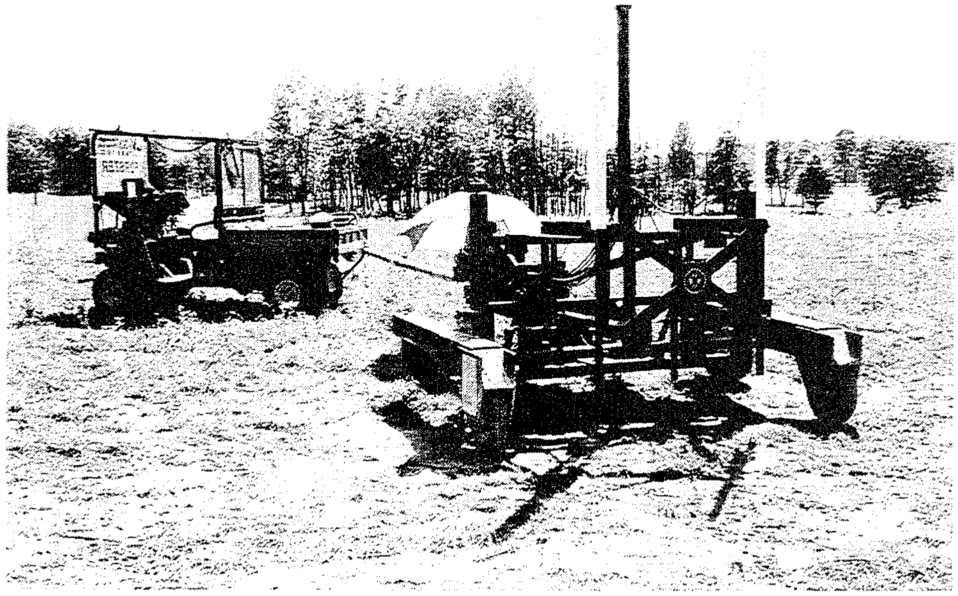
Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	97%	94%	91%
Mistyped	0%	0%	0%

Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	19%	36%	49%
Multiple Targets	22%	44%	44%
Small Targets	15%	25%	42%
Medium Targets	24%	53%	67%
Large Targets	18%	34%	48%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	16%	42%	58%
Projectiles	5%	14%	16%
Mortars	0%	0%	0%
Mines	0%	0%	0%
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.71	1.20	2.01
Standard Deviation	0.33	0.60	1.32

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.37	0.39	0.47
Standard Deviation	0.62	0.58	0.69



Foerster Instruments, Inc.

System Description and Operation. The Foerster system was called the Vehicle Mounted Differential Global Positioning System Controlled Combined Shallow/Deep Search Survey. The system was equipped with an array of FEREX and MINEX Sensors mounted perpendicular to the driving direction. The array is mounted on a towed platform constructed predominantly of wood, with brass and fiberglass composite components. The sensors provide a detection sweep width of 2 m. The platform is towed by a Kawasaki four-wheel drive vehicle that contained a generator and the navigation equipment. Five MINEX Sensors, able to detect all metals and used for land mine detection, were mounted on the front of the array. Four FEREX gradient magnetometer sensors, usually hand-carried, were mounted in the center area of the array. Two modified (elongated) FEREX sensors, called deep search sensors, were mounted at the rear of the array and were designed to extend the detection range to a greater depth. In addition, a data logger attached to a hand-carried FEREX sensor, was used to check the areas near trees. The landscape software presented a map of the entire search area showing specific markings such as corner grid points. It was also able to provide a grid system adapted to the intended tracks of the vehicle such as the 100 by 100 foot grid at JPG.

Survey/Operations Summary. Survey was conducted 13 through 21 August 1994, and covered 20.8 acres.

Support Equipment. One large Ryder rental van.

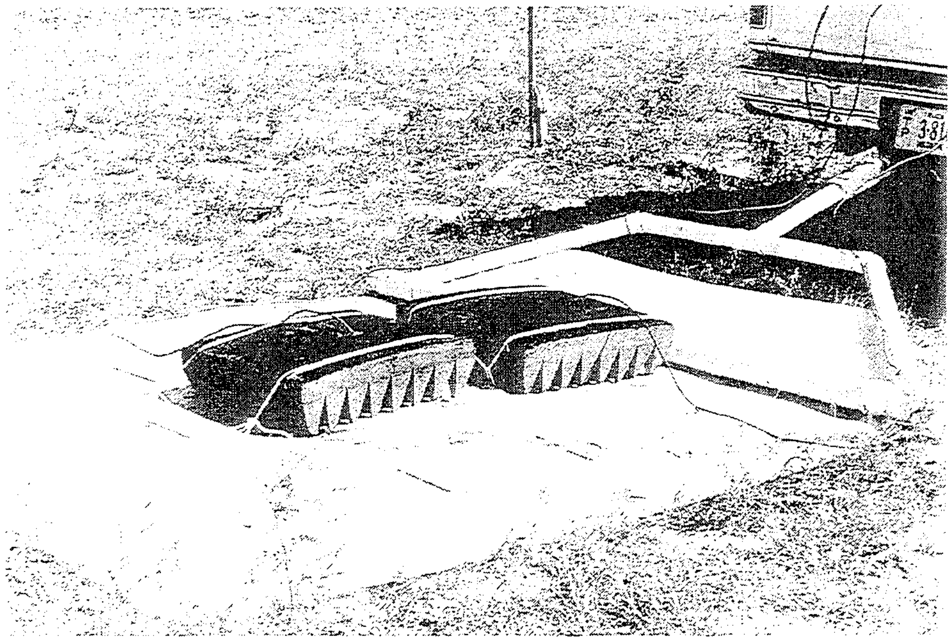
System Limitations. None noted.

Problems Affecting Survey. Some breakage occurred to the wooden components of the towed platform, but they were quickly repaired.

FOERSTER

Note

Demonstrator results for multimodal systems were reported and processed as a single Demonstrator Target Set. Refer to Tab 15 for the results for this demonstrator.



Metratek (Ground)

System Description and Operation. Metratek demonstrated two technologies, a Metratek Model 200 GPR mounted on a plastic sled towed by a four-wheel drive vehicle and an Active Electronic Sensor (AES) mounted on a hand-drawn cart. The Forward Looking Sonar System (FLOSS)/DGPS system was used to monitor vehicle motion along the search grid to mark locations of targets, and to associate GPR and AES sensor data. The search grid provided overlapping coverage so that targets were measured with alternate linear polarization on successive search tracks. The GPR was a wide band, high-resolution, step-chirp, coherent radar with a high speed data recording and real-time processing system. It was normally used in the synthetic aperture mode to provide high-resolution images. The VHF/UHF RF unit covers the 100-800 MHz range. The antenna consists of a pair of orthogonal bow-tie dipoles. The operator was provided with a real-time color display of the radar return. Offline processing used the individual step-chirps and angle aperture to provide dispersion information, which was then used to determine propagation speed through the ground material and derive target depth.

Survey/Operations Summary. Survey was conducted 13 through 21 August 1994, and covered 4.4 acres.

Support Equipment. One Chevy Suburban.

System Limitations. The towed GPR may have problems in mud and heavy vegetation.

Problems Affecting Survey. Many GPR failures occurred. Software problems developed on and off throughout the week.

METRATEK (GROUND)

Note

Demonstrator results for multimodal systems were reported and processed as a single Demonstrator Target Set. Refer to Tab 16 for the results for this demonstrator.

Battelle (Ground)

System Description and Operation. Battelle demonstrated a vehicle-towed GPR. The system was mounted on a Battelle-designed-and-built trailer that was towed by a gasoline powered ATV. The trailer was built using non-ferrous metals because the eventual intent is to also mount magnetometers. The GPR was comprised of a time domain pulser, a transient digitizer, and a sampling oscilloscope. The basic radar was used in conjunction with a controlling IBM compatible computer for recording the data that provided limited real-time feedback. The radar antenna was mounted in the trailer with the computer mounted in the ATV. The trailer had three wheels and measured 4 feet long by 4 feet wide by 1-foot high. The radar Battelle employed was a ground-based GPR system developed by the Ohio State University Electro Science Laboratory (OSU-ESL) for research and development. The radar was originally developed to detect plastic utility pipes and to locate near-surface land mines.

Survey Operations Summary. Survey was conducted 10 through 18 September 1994, and covered 2.0 acres.

Support Equipment. One large van.

System Limitations. System may have problems with rough terrain or heavy vegetation.

Problems Affecting Survey. No significant problems.

BATTELLE (Ground)

Ground | Site: 40 Acre

System Description

Address:	505 King Avenue Columbus, Ohio 43201 (USA)
Demonstration Dates	9/10/94 to 9/18/94
System Name:	OSU Geology Dept. GPR
System Type:	Towed
Sensor Name:	Custom GPR
Sensor Type:	Ground Penetrating Radar
Range (claimed):	Btw 2 ft and 4.99 ft
Navigation System:	Chalk lines
Navigation Type:	Rope/Tape/Odometer
Data Proc. Hardware:	UNIX Workstations
Data Proc. Method:	Image Processing and Pattern Recognition
Area Covered	*5%*

DEMONSTRATION SUMMARY RESULTS

	Detection Ratios		
Critical Radius	1 m	2 m	5 m
Overall	7%	7%	7%
Ordnance	0%	0%	0%
Non-Ordnance	17%	17%	17%

	Error Ratios		
Critical Radius	1 m	2 m	5 m
False Positive	100%	100%	100%
False Negative	100%	100%	100%
Mistyped	*	*	*

	Type Detection Ratios		
Critical Radius	**1 m**	**2 m**	**5 m**
Single Targets	0%	0%	0%
Multiple Targets	*	*	*
Small Targets	14%	14%	14%
Medium Targets	0%	0%	0%
Large Targets	0%	0%	0%

	Classification Ratios		
Critical Radius	**1 m**	**2 m**	**5 m**
Bombs	0%	0%	0%
Projectiles	0%	0%	0%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	-	-	-

[illegible] Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.49	0.49	0.49
Standard Deviation	-	-	-

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	0.15	0.15	0.15
Standard Deviation	-	-	-

* All Targets Declared Indiscriminately As Ordnance

Jaycor

System Description and Operation. The Jaycor system uses a self-propelled vehicle (golf cart) to transport a GPR that operates at a standoff distance. A driver steers the cart; the driver or a passenger operates the radar; a spotter tracks the radar position; and a recorder keeps a record of contact positions relative to the radar, contact identifications, and radar positions. The radar uses frequency-agile coherent pulses capable of classifying target type based on the spectral signature of the returned signals. The system output parameters are target location, return signal amplitude, and return signal spectrum. The system reports location by distance along axis and distance and direction off axis, or by distance and direction relative to the antenna position and axis. The return signal and amplitude and spectrum are used to determine target characteristics. The system consists of one transmit antenna and two receive antennas. The signals from each receive antenna are fed into an In-phase/Quadrature-phase (IQ) circuit to determine the amplitude and phase of a reflected signal as received at each antenna. The differential phase measurements give lateral azimuth information. The time delay measurements give range information and the changing frequency gives spectral signatures for identification as well as increasing the range and enabling the system to detect smaller targets.

Survey/Operations Summary. Survey was performed 16 through 24 July 1994, and covered 18.4 acres.

Support Equipment. One pickup truck.

System Limitations. Limited by soil attenuation.

Problems Affecting Survey. Electronics were rendered inoperable on the last day of the survey when they were drenched by heavy thunderstorms.

JAYCOR

Ground | Site: 40 Acre

System Description

Address:	9775 Towne Centre Drive San Diego, California 92121 (USA)
Demonstration Dates	7/16/94 to 7/24/94
System Name:	Mine Detection Radar
System Type:	Self-propelled
Sensor Name:	JAYCOR
Sensor Type:	Ground Penetrating Radar
Range (claimed):	Less than or equal to 1 ft
Navigation System:	Survey
Navigation Type:	Survey Instrument
Data Proc. Hardware:	UNIX Workstations
Data Proc. Method:	Manual Inspection/Computational Analysis
Area Covered	*46%*

DEMONSTRATION SUMMARY RESULTS

Detection Ratios			
Critical Radius	1 m	2 m	5 m
Overall	0%	0%	4%
Ordnance	0%	0%	4%
Non-Ordnance	0%	0%	5%

Error Ratios			
Critical Radius	1 m	2 m	5 m
False Positive	*	*	100%
False Negative	100%	100%	96%
Mistyped	*	*	0%

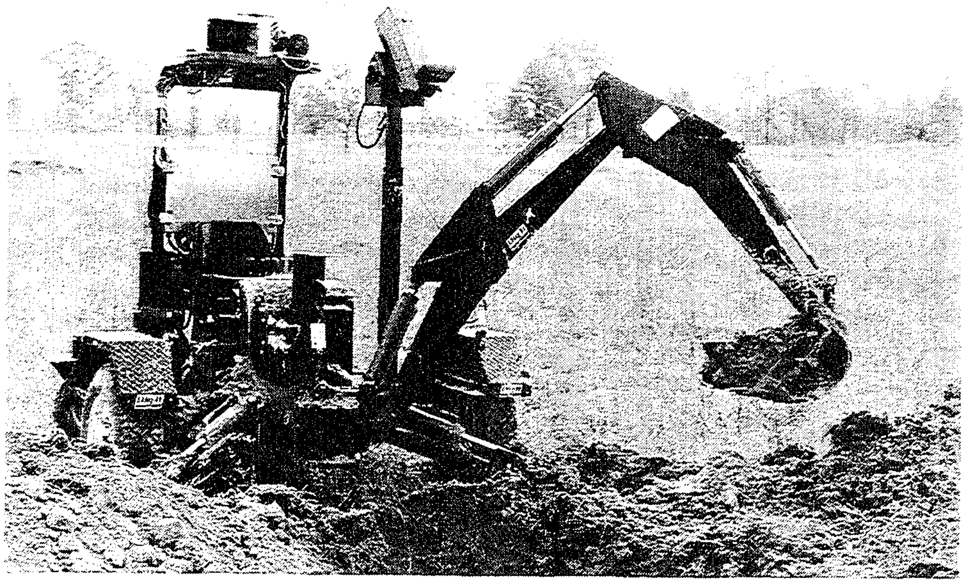
Type Detection Ratios			
Critical Radius	1 m	2 m	5 m
Single Targets	0%	0%	4%
Multiple Targets	0%	0%	0%
Small Targets	0%	0%	4%
Medium Targets	0%	0%	8%
Large Targets	0%	0%	0%

Classification Ratios			
Critical Radius	1 m	2 m	5 m
Bombs	0%	0%	0%
Projectiles	0%	0%	6%
Mortars	0%	0%	0%
Mines	-	-	-
Clusters	0%	0%	0%

Distance Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	4.54
Standard Deviation	-	-	0.45

Depth Accuracy	All Targets - Meters		
Critical Radius	1 m	2 m	5 m
Mean	-	-	-
Standard Deviation	-	-	-

* All Targets Declared Indiscriminately As Ordnance



Benthos, Inc.

System Description and Operation. Benthos remotely operated a Dig-It, a teleoperated controlled excavator/backhoe. The Dig-It was controlled via a 600-foot Kevlar reinforced fiber-optic tether. A hand controller maneuvered the backhoe levers but with sensitive proportional control. The Dig-It was configured with a 12-inch bucket. A DGPS with 1 m to 2 m accuracy was used for navigation. Operations were conducted from a command post where a console and hand controller contained the necessary displays, video monitors, controls, status condition indicators, and power conditioning equipment. Benthos navigated to the assigned targets with DGPS, positioned the bucket on the ground to mark the spot for remediation and then a member of the demonstration support team would precisely locate the target with a MK 26 Ordnance Locator prior to the excavation.

Survey/Operations Summary. Demonstration performed 24 September through 2 October 1994. All assigned targets remediated.

Support Equipment. One large panel truck.

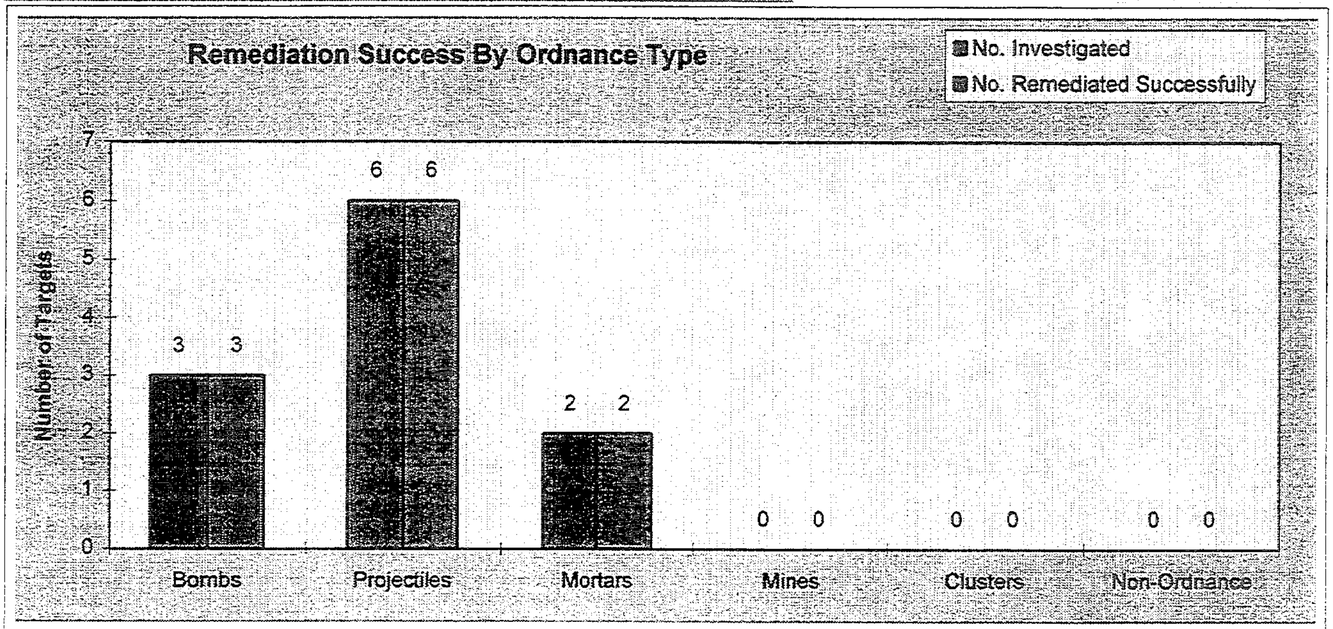
System Limitations. Excavator cannot operate on steep slopes. System has no integral target localization capability.

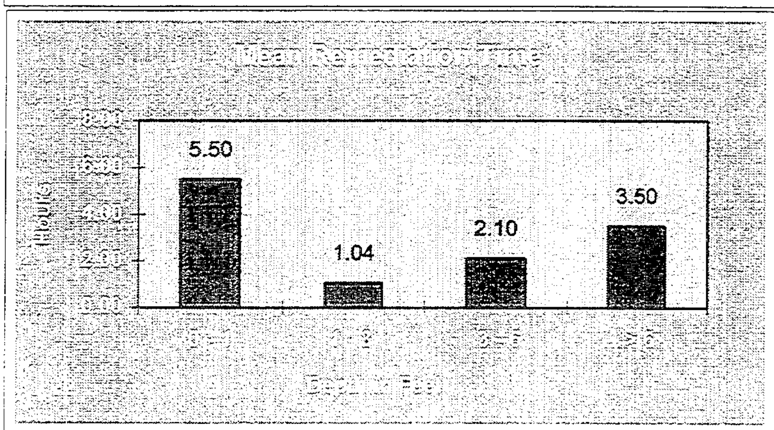
Problems Affecting Survey. No significant problems.

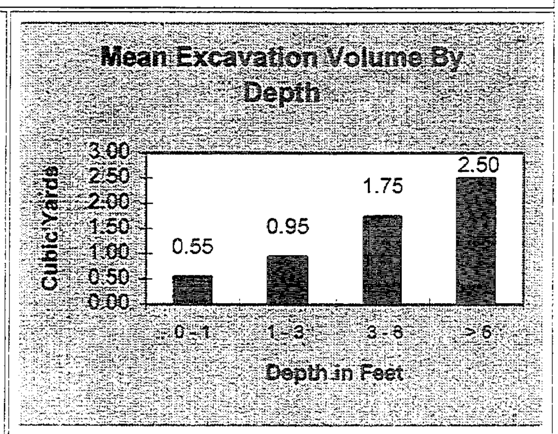
BENTHOS, Inc.
Remediation Demonstrator Results

Description:	Remote Controlled Excavation
Remediation Attempts	11
Successfully Completed	11
Unsuccessful	0

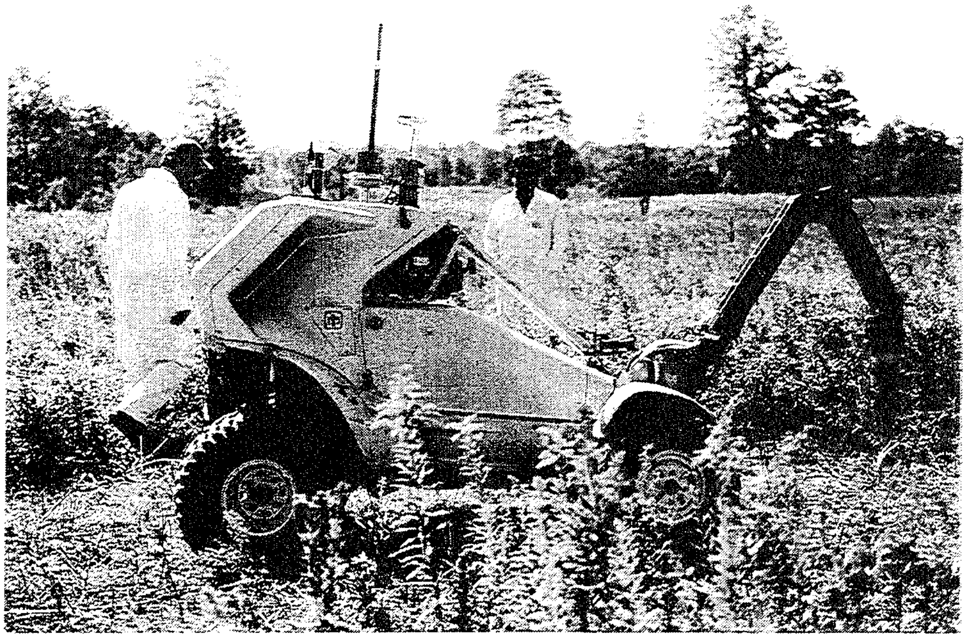
All Targets Successfully Remediated.







* 1 Target at 0.1 foot depth took 10 hours to remediate - No explanation for why it took so long.



Sandia National Laboratories

System Description and Operation. Sandia National Laboratories demonstrated a Remote Telerobotic Vehicle for Intelligent Remediation (RETRVIR). The system integrates model based, sensor-directed robotic manipulation with a remotely operated vehicle. The RETRVIR provides the means for the precise, sensor-controlled excavation of buried materials using specialized tools without the need for large scale excavation. It is powered by an electrically started internal combustion gasoline engine and has two heads that can be attached to a pincer arm. One head was a shovel head for excavating and the other head was a sensor head for sensing magnetic fields. Operations were conducted from a command post where a console and hand controller contained the necessary displays, video monitors, controls, status condition indicators, and power conditioning equipment. The system navigated to the assigned targets with DGPS, searched for the target with the sensor head, positioned the pincer on the ground to mark the area intended for remediation, and used the shovel head for excavation.

Survey/Operations Summary. Demonstration performed 24 September through 2 October 1994; 62 percent of assigned targets remediated.

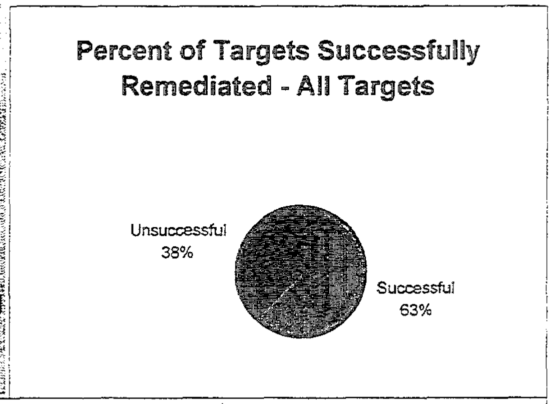
Support Equipment. Command center with tow vehicle.

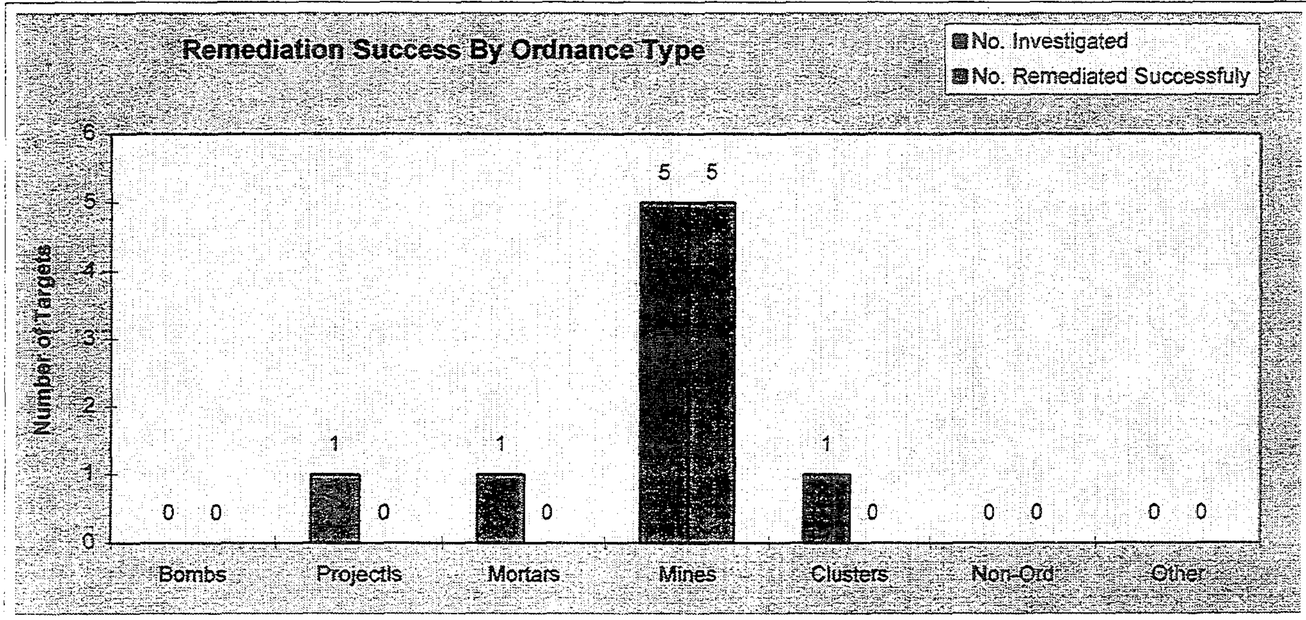
System Limitations. Physical limitations include hard soil, rainy weather, and rough terrain. Sensor limitations based on object size.

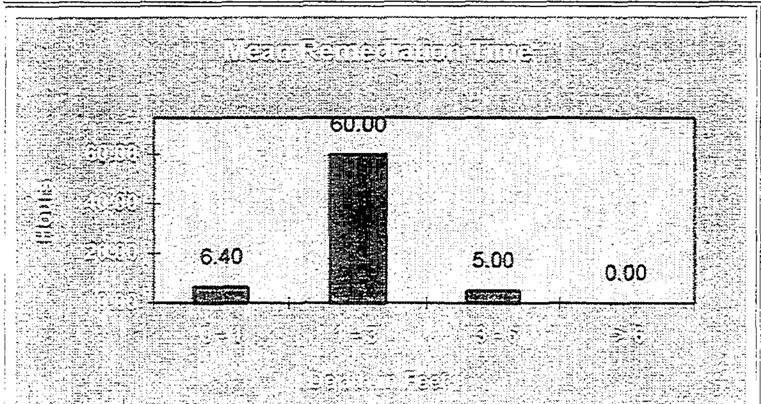
Problems Affecting Survey. Equipment failures caused almost 17.5 hours of downtime. The RETRVIR data link was subject to RF interference from the Tyndall AFB Wright Laboratory remediation system, so the RETRVIR was moved to the 80-acre area.

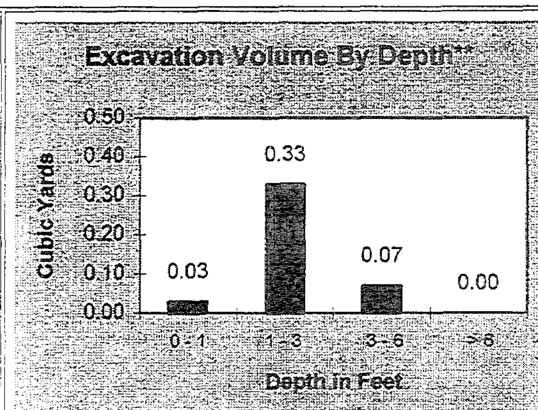
SANDIA NATIONAL LABORATORIES
Remediation Demonstration Results

Description:	Remote Controlled Excavation
Remediation Attempts	8
Successfully Completed	5
Unsuccessful	1 Projectile Not Found 2 Too Deep

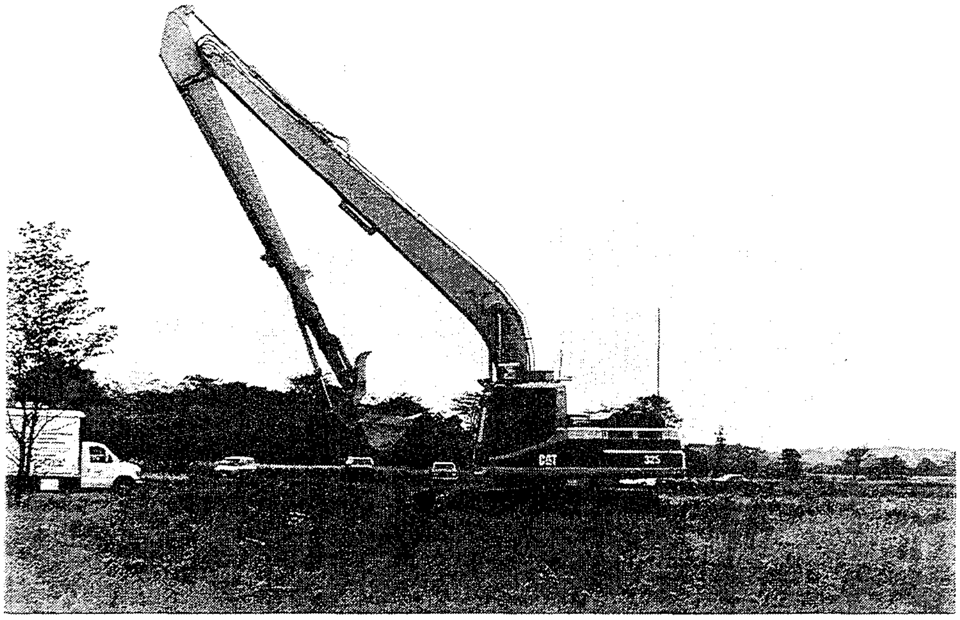








* 1 target (1-3 ft.) was not found in first try, but found on second try 60 hours later. A second target at (0-1 ft.) was not found on first try, but found on second try 24 hours later.
** Searching for the (1-3 ft.) target involved excavating 0.33 Cubic Yards of material.



Tyndall AFB Wright Laboratory

System Description and Operation. The Wright Laboratory's system consisted of a Caterpillar (Cat) 325 long reach excavator, a box van used as a command center, and a John Deere six-wheel ATV to mobilize personnel. The Cat was remotely operated and navigated by means of an Ashtech DGPS. Collision avoidance was accomplished by means of importing the AutoCAD topographic map of the controlled site into the navigation software. The Cat was fitted with a 3-foot general purpose bucket and a clam thumb. Two video cameras were fitted on the Cat. One camera was fitted on the dipper "stick", the other was fitted on the turntable. The command center was outfitted with a 110-volt generator, video monitors, remote controls, GPS base station, and the RF link. The Cat would navigate to the programmed coordinates and establish itself on the target. The stick would then be retracted and the boom lowered to mark the ground at the calculated point for excavation. The excavator would back up and begin to dig over the marked spot. An Unmanned Ground Vehicle System (UGV) was used to augment video capabilities.

Survey/Operations Summary. Demonstration performed 24 September through 2 October 1994; 44 percent of assigned targets remediated.

Support Equipment. One crew-cab pickup truck, UGV, fuel tank, and tools.

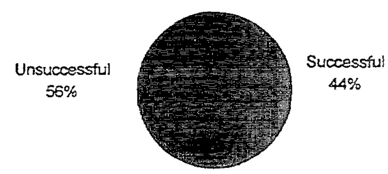
System Limitations. None observed.

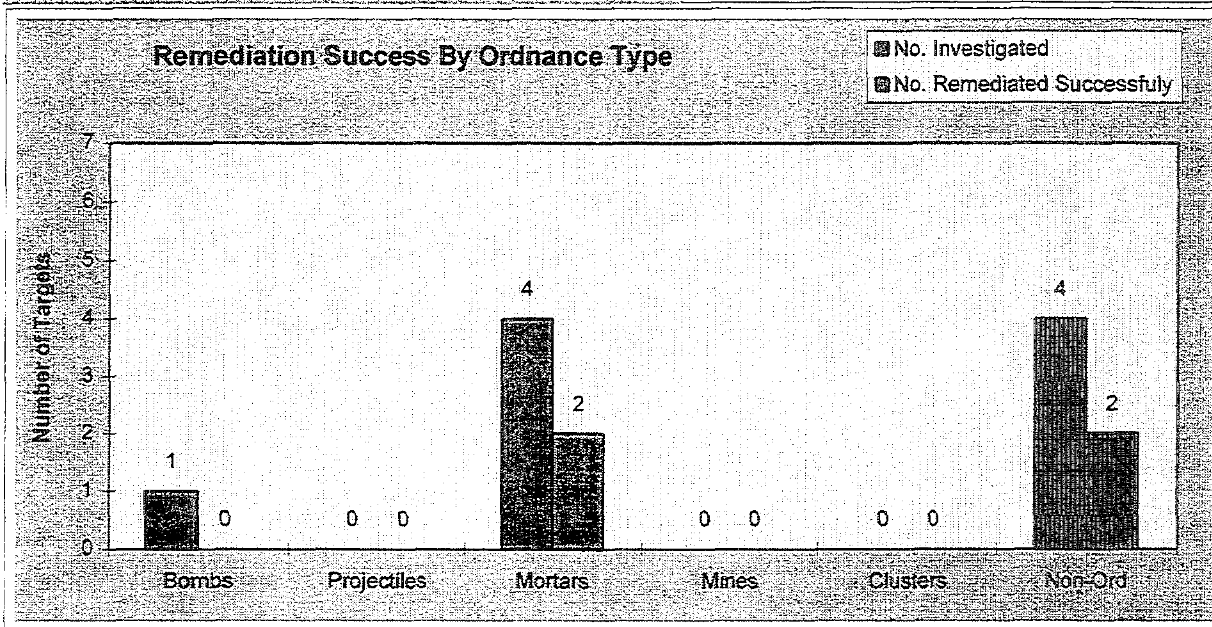
Problems Affecting Survey. Equipment problems caused some periods of downtime. RF data link frequency conflict with Sandia required Sandia to move the 80-acre area.

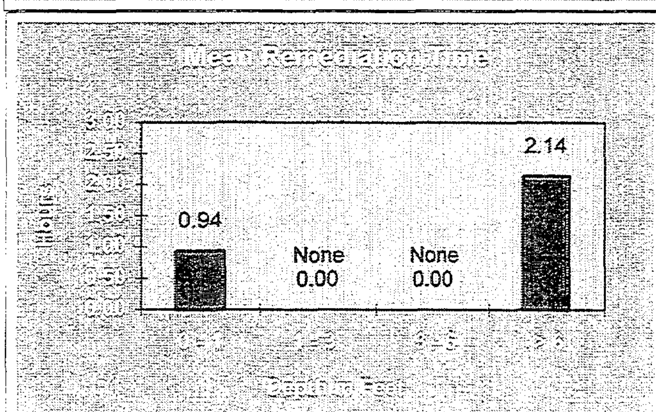
TYNDALL AFB - WRIGHT LABORATORY
Remediation Demonstration Results

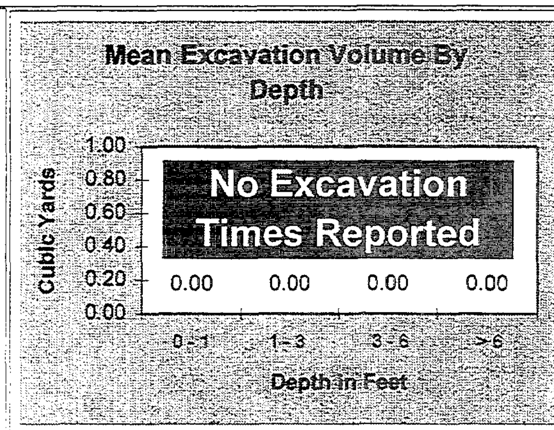
Description	Remote Controlled Excavation
Remediation Attempts	9
Successfully Completed	2 Ordnance
	2 Anomalies (Cnfmd)
Unsuccessful	4 Did Not Excavate*
Other	1 Failed To Locate

Percent of Targets Successfully Remediated - All Targets









* Experienced software and positioning problems during the demonstration, and did not attempt remediation at four targets reported as unsuccessful.

Glossary

Airborne Systems
Demonstrator systems using sensors suspended 3 m or more above the ground, including those using airborne platforms (fixed wing and rotary wing) and those using ground-towed aerial platforms.

Baseline Non-Ordnance Set (*BN*)
Subset of the Baseline Target Set consisting of only emplaced non-ordnance targets, that is, targets of non-ordnance type. No baseline targets are of the others type.

Baseline Ordnance Set (*BO*)
Subset of the Baseline Target Set consisting of only ordnance targets, that is, emplaced targets of either single or multiple type.

Baseline Target Set (*B*)
All baseline (emplaced) targets of a single test site, that is, either the 40-acre or 80-acre area. Baseline targets include ordnance and non-ordnance items.

Classification Ratio
Bombs, clusters, mines, mortars, and projectiles are classes of baseline targets.

Classification Ratio for Bombs (C_{bomb})
Number of matched targets classified as bombs divided by the total number of baseline bombs. This ratio represents a demonstrator's capability in detecting and identifying bombs.

Classification Ratio for Clusters ($R_{cluster}$)
Number of matched targets classified as clusters divided by the total number of baseline clusters. This ratio represents a demonstrator's capability in detecting and identifying clusters.

Classification Ratio for Mines (C_{mines})
Number of matched targets classified as mines divided by the total number of baseline mines. This ratio represents a demonstrator's capability in detecting and identifying mines.

Classification Ratio for Mortars (C_{mortar})
Number of matched targets classified as mortars divided by the total number of baseline mortars. This ratio represents a demonstrator's capability in detecting and identifying mortars.

Classification Ratio for Projectiles ($C_{projectile}$)
Number of matched targets classified as projectiles divided by the total number of baseline projectiles. This ratio represents a demonstrator's capability in detecting and identifying projectiles.

Cluster
Two or more small ordnance items emplaced at a single location and considered to be a single target.

Critical Angle
The difference in azimuth angle (or declination angle) between a demonstrator target and a baseline target for determining match in azimuth angle (or declination angle).

Critical Height
The vertical distance between a demonstrator target and a baseline target for determining depth match.

Critical Radius
The horizontal distance measured from the center point of a demonstrator target to a baseline target projected as a rectangle on the surface X-Y plane for determining location match.

Demonstrator Non-Ordnance Set (DN)
Subset of Demonstrator Target Set consisting of only non-ordnance targets, that is, targets of either the non-ordnance or others type, as reported by the demonstrator.

Demonstrator Ordnance Set (DO)
Subset of Demonstrator Target Set consisting of only ordnance targets, that is, targets of either the single or multiple type, as reported by the demonstrator.

Demonstrator Target Set (D)
All targets reported by a single demonstrator.

Detection Accuracy
The statistical mean and standard deviation representing the distribution of miss distances for targets matched in both position and depth.

Detection Ratio for Large Targets (R_{large})
Number of matched targets of large size divided by the total number of baseline targets of large size within the grid cells surveyed. The targets must match in size only; targets may or may not match in type or class. This ratio represents a demonstrator's capability in detecting and identifying large targets.

Detection Ratio for Medium Targets (R_{medium})
Number of matched targets of medium size divided by the total number of baseline targets of medium size within the grid cells surveyed. The targets must match in size only; targets may or may not match in type or class. This ratio represents a demonstrator's capability in detecting and identifying medium targets.

Detection Ratio for Multiple Targets ($R_{multiple}$)
Number of detected multiple targets divided by the total number of baseline multiple targets within the grid cells surveyed. This ratio represents a demonstrator's capability in detecting multiple ordnance targets.

Detection Ratio for Non-Ordnance Targets ($R_{non\text{-}ord}$)
Number of matched non-ordnance targets divided by the total number of baseline non-ordnance targets within the grid cells surveyed. This ratio represents a demonstrator's capability in detecting non-ordnance targets.

Detection Ratio for Ordnance Targets (R_{ord})
Number of matched ordnance targets divided by the total number of baseline ordnance targets within the grid cells surveyed. This ratio represents a demonstrator's capability in detecting ordnance targets.

Detection Ratio, Overall (R_{all})
Number of matched targets divided by the total number of baseline targets within the grid cells surveyed. This ratio generally represents a demonstrator's detection capability.

Detection Ratio for Single Targets (R_{single})
Number of detected single targets divided by the total number of baseline single targets within the grid cells surveyed. This ratio represents a demonstrator's capability in detecting single ordnance targets.

Detection Ratio for Small Targets (R_{small})
Number of matched targets of small size divided by the total number of baseline targets of small size within the grid cells surveyed. The targets must match in size only; targets may or may not match in type or class. This ratio represents a demonstrator's capability in detecting and identifying small targets.

Differential Global Positioning System (DGPS)
A navigation system that uses a mobile GPS receiver in conjunction with a stationary reference GPS receiver and processing software to reduce the error inherent in non-encrypted GPS signals and attain enhanced positioning accuracies.

Error Ratios
Measures of a demonstrator's ability to discriminate between ordnance and non-ordnance targets, consisting of False Negative, False Positive, and Mistyped Ordnance Ratios.

False Negative Ratio *(FNR)*
Number of false negative targets divided by the sum of the numbers of false negative targets and true positive targets. This ratio is representative of the probability that a demonstrator will identify a false target as ordnance. A demonstrator with a low score (0) does well.

False Positive Set (*FP*)
Baseline non-ordnance targets that are detected by the demonstrator but identified as ordnance (either the single or multiple type). This represents an incorrect classification requiring unnecessary remediation. *A low number is desirable.*

False Positive Ratio *(FPR)*
Number of false positive targets divided by the number of detected baseline non-ordnance targets. This ratio, which is the percentage of detected baseline non-ordnance targets declared as ordnance, represents how likely a demonstrator will distinguish non-ordnance from ordnance. A demonstrator who scores low (0) does well and has the capability to distinguish non-ordnance from ordnance. A demonstrator who scores high (1) does poorly and tends to declare everything detected to be ordnance.

Large Target
A target 200 mm or larger in diameter.

Magnetometer
For classifying sensors in this study, any of a family of active or passive ferrous object detectors or electromagnetic induction casts.

Matched Target Set (*E*)
Baseline targets that the target matching algorithm determines to be detected targets.

Matching Function
An evaluation function used to compare different matches of targets.

Matching Indicator
A binary function that represents the match or mismatch condition for each target attribute. For a given target pair *(a, b)*, the matching indicator for the *i*-th attribute m_i is equal to 1 if there is a match in the *i*-th attribute. Otherwise, it is set to 0.

Mean Depth (MH)
The average depth error between matched target pairs.

Mean Distance *(MD)*
The average distance between matched target pairs.

Medium Target
A target 100 mm or larger, but less than 200 mm in diameter.

Mistyped Ordnance Ratio *(MR)*
Number of mistyped ordnance targets divided by the number of detected baseline ordnance targets. This ratio, which is the percentage of detected baseline ordnance targets declared as non-ordnance, represents the percentage of detected ordnance that would be missed due to demonstrator's identification error. A demonstrator who scores low (0) does well because ordnance is identified correctly. A demonstrator who scores high (1) does poorly as most of the ordnance detected will not be investigated as ordnance targets.

Mistyped Target Set (*MT*)
Baseline ordnance targets that are detected by the demonstrator, but are identified as non-ordnance (of either the non-ordnance or others type). This represents actual ordnance targets that are incorrectly identified as non-ordnance. *Zero or a small number is desirable.*

Multimodal System
A demonstration system using multiple platforms, such as a vehicular towed array and a man-portable magnetometer.

Multiple Target
Two or more individual targets located in close proximity relative to the critical radius.

Multi-sensor System
A demonstration system using multiple sensor technologies, such as a Ground Penetrating Radar (GPR) with a magnetometer, or a GPR and with an infrared sensor.

Non-Ordnance
In this study, non-ordnance includes ordnance-related objects such as bomb fins, and fragmentation, as well as common items such as wire, engineer's stakes, metal drums, and other ferrous objects.

Ordnance
In this study, ordnance is limited to intact, inert bombs, projectiles, practice munitions, rocket warheads, mortar rounds, submunitions, and land mines.

Platform
A vehicle or structure that carries the UXO detection sensors; including fixed wing and rotary wing aircraft, aerial structures suspended above the ground, self-propelled vehicles, vehicle-towed and man-towed trailers, and man-portable systems.

Small Target
A target measuring less than 100 mm in diameter.

Standard Deviation of Location (σ_D)
An indicator of the spread of the distribution of distances between matched target pairs, equal to the root mean square of distance.

Target Attribute
A target feature for identification.

Target Azimuth Angle
Angle between the target center axis and true north in the horizontal plane.

Target Azimuth Angle Match
A demonstration target *a* matches a baseline target *b* in azimuth angle if the difference between the two azimuth angles is less than or equal to the critical angle $\Delta \alpha$.

Target Class
Mortar, projectile, bomb, mine, cluster, or others. In this study, rocket warheads are included in the projectile class, and submunitions are included in clusters or others, as appropriate.

Target Class Match
A demonstration target *a* matches a baseline target *b* in class if both of them are of the same class.

Target Declination Angle
Angle between the target center axis and the horizontal plane.

Target Declination Angle Match
A demonstration target *a* matches a baseline target *b* in declination angle if the difference between the two declination angles is less than or equal to the critical angle $\Delta \phi$.

Target Depth
Elevation measured from the mean sea level (MSL) to the center point of the target.

Target Depth Match
A demonstration target *a* matches a baseline target *b* in depth if the vertical distance between *a* and *b* is less than or equal to the critical height Δh.

Target Location
Target position in Universal Transverse Mercator (UTM) coordinates.

Target Location Match
A demonstration target *a* matches a baseline target *b* in location, if the horizontal distance between *a* and *b* is less than or equal to the critical radius Δr. The position of baseline target *b* is considered to be the rectangle that is the projection in the X-Y plane of a cylinder that circumscribes the target.

Target Matching Conditions
A demonstration target matches a baseline target if their attributes coincide, or when location matching takes precedence. Tolerance limits can be introduced for attributes with numeric data types, that is, location, depth, and azimuth and declination angle.

Target Pair
A one-to-one mapping between a demonstrator target and a baseline target.

Target Set
A list of all the targets contained within a single demonstration area.

Target Size
Small, medium, or large.

Target Size Match
A demonstration target *a* matches a baseline target *b* in size if both of them have the same size.

Target Type
Single, Multiple, Non-Ordnance, or Others.

Target Type Match
A demonstration target *a* matches a baseline target *b* in type if both of them have the same type.

True Positive Set (*TP*)
Baseline ordnance targets that are detected by the demonstrator and identified as ordnance (of either the single or multiple type). This represents the ordnance targets identified by a contractor that correctly match baseline ordnance targets. *A large number is desirable.*

Undetected Non-Ordnance Set (*UN*)
Baseline non-ordnance targets that are not detected by the demonstrator. While not causing any ordnance risk, this represents an insensitivity in the instrumentation. *A low number is desirable.*

Undetected Ordnance Set (*UO*)
Baseline ordnance targets that are not detected by the demonstrator. This represents unremediated ordnance risks, and *a low number is desirable*.